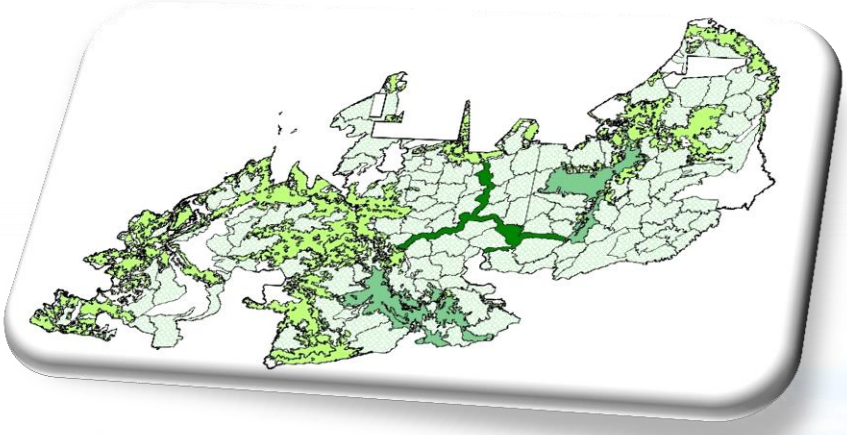
Small Mammals of the Planted Forest Zone of Sarawak, East Malaysia; an Assessment of Dispersal Ability and Response to Habitat Fragmentation

PhD thesis submitted in fulfilment of the degree Doctor of Forestry Science

ANTONY BRUCE SHADBOLT

2014

New Zealand School of Forestry
University of Canterbury
Christchurch
New Zealand



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Certification

I, Antony Bruce Shadbolt, declare that this thesis, submitted in fulfilment of the requirements for the award Doctor of Philosophy, in the School of Forestry, at The University of Canterbury is wholly my own work. With the exception of parts of Chapter 3 and Appendix 4 (refer below) it does not include any material published by another person without due reference within the text. The fieldwork presented in this thesis was performed by the author, and all photographs were taken by the author except where acknowledged. This document has not been submitted for qualifications at any other academic institution.

Chapter 3 contains data that has been previously published in a paper co-authored with Roslina Ragai, conservation officer with Grand Perfect Sdn. Bhd. Rose's input into this paper involved a great deal of help and advice during with the fieldwork component of the research, and reviewing of the finished manuscript. This paper was subsequently published in the international journal 'Biodiversity and Conservation' (Shadbolt and Ragai 2010) and is also included in Appendix 4 of this thesis in its published format along with a signed co-authorship form. Use of this data in this thesis was made possible with kind permission from Springer Science and Business Media.

Antony Bruce Shadbolt

16th June 2014

Abstract

In recent years a push to establish pulpwood plantation forestry in Sarawak, East Malaysia with *Acacia mangium* has been identified as a means to relieve pressure on the State's diminishing natural forest resource whilst providing 1) economic wealth for a developing economy 2) community development, and 3) biodiversity conservation outside the protected area network. In a specially designated 504,000 hectare Planted Forest Zone (PFZ) a range of broad-scale landscape planning initiatives have been implemented in an attempt to conserve a representative sample of biodiversity across the plantation landscape. The effects of forest modification and fragmentation have been widely reported in the literature for mammals, and in this study, non-volant small mammals were fitted with tracking spools and/or radio collars and released into small forest remnants outside of their home ranges to measure response to unfamiliar habitats, forest edges and various scales of habitat fragmentation during simulated dispersal events

Medium sized patches exhibited the greatest species diversity and abundance, whereas the largest forest areas hosted the largest population of brown spiny rat (*Maxomys rajah);* a species that is identified as vulnerable across its natural range. Small forest patches of c.1.00 ha that had been exempt from clearing during plantation establishment are likely to be species poor and host small populations of extant species only. All species were found to make extensive use of downed woody debris for movement, and showed varied responses to a range of habitat edges including forest roads, acacia plantation compartments, old haul trails, clearings and riparian areas. Two species of treeshrew; long-footed treeshrew *(Tupaia longipes)* and painted treeshrew *(T. picta)* were shown to be able to move between the forest patch and the acacia forest while the same edges were shown to pose barriers to

the brown spiny rat *(M. rajah)* and large treeshew *(T. tana)* illustrating the different ways that species may perceive and use habitat features such as corridors.

Despite *T. picta* being common in the PFZ, comparatively little has been published on its ecology and behaviour compared with the other Bornean tupaiids. Therefore this study also reports on the movement and behaviour of this species within its own home territory as revealed from both radio telemetry and spool-and-line tracking. Home range size, dimension, average daily movement distances and nest site construction was found to be similar to other Tupaiids studied in secondary forests in Sabah, and home ranges were found to be dictated by anthropogenic landscape features such as forest roads and open areas across which no movement was recorded. Painted treeshrews were found to favour logs and fallen woody debris as movement substrates and spend the large majority of their movement at ground level. Camera trapping revealed possible interspecific nest sharing between the painted treeshrew and the three-striped ground squirrel *(Lariscus insignis)*, fuelling the debate on whether or not treeshrews construct their own nests or use nests constructed by squirrels.

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Abbreviations

AIDS	Acquired Immune Deficiency Syndrome
ANOVA	Analysis of Variance
BPP	Borneo Pulp & Paper
CITES	Convention on International Trade of Endangered Species of Wild Fauna and Flora
DBH	Diameter at Breast Height
FAO	Food & Agriculture Organisation
FSC	Forest Stewardship Council
GP	Grand Perfect Sdn Bhd
GPCon	Grand Perfect Sdn Bhd Conservation Department
GPS	Geographic Positioning System
KNF	Kakus Nursery Forest
ITTO	International Tropical Timber Organisation
MC&I	Malaysian Criteria & Indicators for Forest Management Certification
MDF	Mixed Dipterocarp Forest
MFMA	Model Forest Management Area
NCR	Native Customary Rights
NFC	National Forest Council
NFP	National Forest Policy
NSC	National Steering Committee
NSSB	Natural Science Society Bintulu
PFE	Permanent Forest Estate
PFP	Planted Forests Project
PFZ	Planted Forest Zone
Sdn Bhd	(Malay) Sendirian Berhad (Private Limited)

SEG	Spatial Ecology Group
SFI	Sabah Forest Industries
SFM	Sustainable Forest Management
SNCF	Samarakan Nursery Conservation Forest
SPF	Sarawak Planted Forests
TEA	Tropical East Asia
TPA	Totally Protected Area

Acknowledgements

Much thanks to all the management of Grand Perfect Sdn Bhd., Sarawak Planted Forests, and Sarawak Forestry for allowing me the opportunity to work with them and their team in the Planted Forest Zone, for organizing the field expeditions, and for all the invaluable information and advice offered. I especially wish to thank the Grand Perfect Conservation team; particularly Rose Ragai, Joanas Unung, Azizan Juhin, Alex Jukie and Beldin Giman and all of the field staff for their hard work, support, advice and patience in the field. Thanks also go to the Sarawak Timber Association (STA), and particularly to Barney Chan and Peter Kho for their parts in giving me the opportunity to carry out research work in Sarawak, and especially for their continued support and hospitality. Out of respect and appreciation for this dynamic team I have included an additional appendix at the end of this thesis that captures the special people and moments that I am forever grateful for.

The Lincoln University Spatial Ecology Group (SEG) was of great help. I owe my great thanks particularly to Dr Hannah Buckley and Dr Belinda Whyte for their generous and helpful statistical advice.

Thank you also to the editorial board of the Journal Biodiversity and Conservation for allowing me to re-use published data (Shadbolt and Ragai 2010; Appendix 4) relating to movement activity of the brown spiny rat. This was made possible with kind permission from Springer Science and Business Media. Being able to include and re-analyse this important data in my thesis was invaluable.

Thanks to my supervisory team, Dr Hamish Cochrane, Dr David Norton and Dr Robert Stuebing for all their support and advice over the last seven years. Their advice and support has been critical in completing this course of study. I also wish to thank the University of Canterbury Scholarships Office, the New Zealand Postgraduate Study Abroad Award and to

the McKelvey Fund (New Zealand School of Forestry) for their generous funding, without which this ongoing research program would not be possible. A big thanks too, to the School of Forestry Administrator, Jeanette Allen for all her support and patience over many years.

Thanks also must go to Dr Carol King (University of Waikato) and Professor Raphael Didham (University of Western Australia). Due to their detailed feedback, advice and encouraging words, I believe this thesis has become much stronger, more focussed and easier to read than it would have been without their valuable input.

Throughout the course of this research I have needed to be separated from my family for extended periods of time, usually during Christchurch winters, while I conducted fieldwork sessions in a more tropical climate. Their understanding and support cannot be measured, and cannot be thanked enough. I thank my partner Jane and our children Laura and Sam for their patience and support through five cold winters, earthquakes and countless late nights in front of the computer.

Finally I owe my great appreciation to my employer, the Christchurch City Council for their continued support of my research interests and ongoing personal development. As such I would particularly like to thank my team leaders Dennis Preston, Roy Eastman and Fiona McKay, and my managers Keith Davison, Kevin Locke and Kevin Mara. Without their support I would not have been able to pursue postgraduate study at both the Masters and PhD level.

Preface

With Sarawak's Totally Protected Area (TPA) network unlikely to exceed ten percent of its total land area and made up of isolated forest reserves, forest and wildlife managers are not able to rely solely on these areas for the protection and conservation of the State's species that they are assumed to cater for. The argument has often been put forward that plantation forestry could reduce pressure on natural forest, and at the same time provide positive outcomes for the management and conservation of biodiversity. If this is indeed the case, such a plantation landscape would provide a significant extension of The State's TPA network which is currently under considerable pressure in terms of its area restriction, isolated nature of its component reserves, illegal logging, poaching, shifting cultivation, fire and storm damage, species decline and local extinctions.

As part of this paradigm shift towards managing plantation forest for biodiversity values, the Sarawak Forest Department has embarked on the Planted Forests Project (PFP), part of which includes a fast growing *Acacia mangium* plantation in a specially designated 504,000 ha Planted Forest Zone (PFZ) in the Bintulu Division of the State. In terms of maintaining long term biodiversity values across the PFZ, it is planned that approximately 35% of the landscape will be reserved as strategically located conservation set-asides. These set-asides include three large (>10,000 ha) forest reserves, river and stream buffers 6 – 500 m in width, steep land, wetlands, and remnant forest patches embedded within each acacia compartment to act as lifeboats for biodiversity. In 2007, Discover Magazine listed the Planted Forests Project's PFZ as "one of the six most important scientific experiments in the world", in recognition of the goal of protecting biological diversity whilst allowing the local community the enjoyment of economic benefits from a production landscape.

Recent biodiversity inventories have shown that approximately 60% of the local forest vertebrate fauna were found within the acacia plantation compartments, and was similar to that of secondary forests. Furthermore, rather than the PFZ landscape consisting of a monoculture of acacia, a mosaic of acacia, habitat patches and wildlife corridors and river buffers has the potential to maintain a representative sample of the extant biodiversity across the wider landscape. However in order to achieve this goal the landscape of the PFZ will need to be managed in such a way that the viability of wildlife populations is secured in the long term.

This thesis investigates the ability of non-volant small mammals to utilise the habitats contained within PFZ landscape in terms of their movement behaviour, their use of fine scale landscape elements, and their response to a range of habitat edge features, recognising that not all species will respond or cope with the degree of habitat modification equally. Therefore some species are likely to be more or less threatened by habitat conversion and/or fragmentation than others, and as a consequence their populations are likely to more or less likely to persist in the long term across the PFZ landscape.

Chapter One provides an introduction to forest resources of Sarawak and discusses the range of impacts affecting them with particular regard to effects on biodiversity values and ecological processes. It discusses the history of forest usage and management by the indigenous peoples of Borneo and also the commercial exploitation of forests for timber resources that commenced in the late 20th century; exploitation that has led to a current trend towards plantation forestry as a means to ease pressure on natural forests and maintain a sustained supply of raw materials to wood based industries. The concept of the Planted Forest Zone (PFZ); an initiative of the Sarawak State Government which aims to balance the need for biodiversity conservation with the need to maintain the supply of the raw materials is introduced here.

Chapter Two is the first of the chapters that describes fieldwork carried out in the PFZ between 2006 and 2010. This chapter presents the results of successive small mammal trapping sessions in remnant forest patches of various sizes that are embedded within a matrix of fast growing acacia plantation compartments. Although the primary purpose of the small mammal trapping in these forest patches was to capture live animals for spool-and-line tracking and radio tracking studies (see subsequent chapter outlines), the results are illustrative of the broad concepts of landscape ecology and biogeography in that the smaller patches were found to have both lower species richness and lower carrying capacity compared to larger, more continuous forest areas.

Chapter Three is the first of the chapters that discusses the results of spool-and-line tracking of small non-volant mammals moving through novel forest patches. Here small mammals are translocated to small patches of remnant forest outside of their home ranges, fitted with spool-and-line tracking devices and released in order to simulate dispersal behaviour and in doing so to observe responses to a range of habitat edge features including acacia compartments, roads, haul trails, clearings and riparian environments. Control groups of animals are also released at their points of capture to enable a comparison of movement behaviour between home territories and novel patches where they are exposed to a range of edge features. From this method an insight is gained into how different species may be affected by varying degrees and causes of habitat fragmentation.

Chapter Four focusses on the behaviour of the little-studied painted treeshrew *(Tupaia picta).* This study uses radio telemetry to observe daily activity patterns, home range behaviour, nest use, and also behaviour of individuals translocated to and released in novel patches outside of their home ranges. Translocated animals were found to be capable of long distance movements within relatively short timeframes, and often crossed into and remained in the exotic acacia forest for considerable lengths of time.

In this study, radio-tracking and camera trapping are also used to locate and record the use of multiple nest sites that are distributed around the individuals' home range. Evidence is presented that suggests possible inter-specific nest sharing with a species of ground squirrel (three-striped ground squirrel; *Lariscus insignis*), resurrecting the mystery of which species indeed constructs treeshrew nests; treeshrews or squirrels?

Chapter Five synthesises the four preceding chapters into the broad conclusions and recommendations for the management of wildlife populations across the modified landscape of the PFZ. It also outlines a series of imperatives for ongoing monitoring, and outlines future research possibilities that could provide vital data in support of the hypothesis that small islands of remnant forest do act as virtual lifeboats for biodiversity, and thus provide real value for conservation within the PFZ and other such areas. If well managed, such research and monitoring activities will help ensure the Planted Forests Project remains one of the most important scientific experiments in the world, as described by Discover Magazine in 2007.

CHAPTER 1

Introduction to the Natural and Planted Forest Resources of Sarawak, East Malaysia: Implications for the Management and Conservation of the State's Indigenous Biodiversity

Executive Summary

Forest exploitation, degradation and deforestation in the tropics is increasing at an alarming rate and these forests are estimated to be shrinking at a rate of 5% per decade. This coupled with illegal hunting, habitat fragmentation, shifting cultivation, storm and fire damage is having significant adverse impacts on biodiversity, and in Sarawak protected areas are losing species with some Totally Protected Areas no longer containing primate fauna. In recent years a push to establish plantation forestry in Sarawak has been identified as a means to relieve pressure on the State's diminishing natural forest resource whilst providing 1) economic wealth for a developing economy 2) community development, and 3) biodiversity conservation outside the protected area network. A range of broad-scale landscape planning initiatives have been implemented by the Conservation Department of Grand Perfect Sdn. Bhd; a consortium of three local timber companies engaged by the Sarawak State Government as the primary contractor tasked with the establishment of a the specially designated 504,000 hectare Planted Forest Zone (PFZ) in the Bintulu Division, Sarawak, east Malaysia. These initiatives aim to conserve a representative sample of biodiversity across the plantation landscape, and as a result the PFZ of Sarawak was described in 2007 as being one of the six most important scientific experiments in the world.

Key Words: *Acacia mangium*, landscape ecology, plantation forestry, shifting cultivation, tropical forestry, wildlife management

Title Page Image: Logs stockpiled on the banks of a Sarawak river (Sungai Sebauh), Bintulu Division, Sarawak, East Malaysia (Photograph A. Shadbolt 2009).

1.1 Introduction

In recent years a push to establish planted forests in tropical ecosystems has been promoted as a means to ensure both sustainable forest management (SFM) (ITTO 2007), and to relieve pressure on natural forests (Barber 1998). This chapter provides an introduction to the forest resources of Sarawak, Malaysia, and discusses the development of planted forests, and how such forests are being promoted as a land use that provides revenue for national development, whilst also providing for landscape scale forest management with potential positive outcomes for the conservation of biological diversity.

In terms of biodiversity, tropical forests contain perhaps 80% of the worlds' plant species (Evans and Turnbull 2004), but are reported to be shrinking at a rate of 5% per decade as croplands, pastures and plantation forestry steadily replace them (Gibson *et al.* 2011); a trend likely to continue for the next 30 to 50 years (Chomitz 2007). Indeed, in all three International Tropical Timber Organisation (ITTO) producer regions; Africa, Latin America and Asia, forest coverage has been declining since the inception of the ITTO in 1985. In Asia this has seen a drop from 41.4% total land area in 1985 to 35.5% in 2005; a removal of approximately 14.25% of the original 1985 area estimate. However this trend does not account for rapidly progressing forest degradation within still standing forests (Nakagawa *et al.* 2007) which could see the condition of natural forests deteriorate far below their original condition before any reduction in forest coverage would be recorded (ITTO 2007). Biodiversity loss has therefore become one of the most pressing issues facing both the survival and prosperity of human society (Wu 2007).

Being one of the world's 12 most biodiversity-rich countries and ranking fourth in Asia behind China, India and Indonesia, Malaysia has a wealth of natural resources (Latif and Zakri 1998). At 12.45 million hectares (124,499 square kilometers), Sarawak is Malaysia's largest state (Jomo *et al.* 2004), and together with Sabah forms East Malaysia on the island of Borneo (Figure 1.1); the world's third largest island after Greenland and New Guinea. Sarawak, situated in northwestern Borneo, shares many of the biogeographical characteristics of Kalimantan, Indonesia, which lies across a loosely-defined border to the south and east (Brookfield *et al.* 1995; Jackson 1968). Borneo has long been famous for its forests (Brookfield *et al.* 1995), and the natural forests of Malaysian Borneo host biodiversity that may be of considerable importance to mankind (Glyn 1998), with recent research focusing on the latex of the bintangor tree *(Calophyllum spp.)*; a timber tree that is now protected and whose latex is thought to potentially hold a cure for AIDS (Acquired Immune Deficiency Syndrome) (Hazebroek and Morshidi 2001). High temperatures and an annual rainfall of 2000 to 7000mm promote a diverse but characteristically luxurious and continuous plant growth that has dubbed Borneo 'the evergreen island' (Jackson 1968) and has attracted visiting plant collectors from relatively early times (Ashton 1968).

Not surprisingly, an immense richness of flora and fauna has made Borneo a centre of biodiversity in Southeast Asia (Hazebroek and Morshidi 2001; Inger 2007), with over 1000 species of terrestrial vertebrates (Stuebing 2005), and in excess of 2500 tree species in Sarawak alone (Hazebroek and Morshidi 2001). Here the cumulative number of timber species capable of attaining a diameter of four inches or more continues to rise steeply even after 80 inventory samples, illustrating the great diversity and complexity of timber species present in the States forests, with rarer species appearing to be distributed throughout the wider forest area (FAO

1973). For its land area, Sarawak also has among the highest number of animal species in the world for an area of its size (Gumal *et al.* 2008)

Figure 1.1: Map of Borneo showing the Malaysian States of Sabah and Sarawak, the Sultanate of Brunei, and the Indonesian State of Kalimantan.

The name Borneo now evokes a vision not just of luxurious forests, but also of a constantly changing landscape (Potter 2006). As recently as the mid 1800's over 95% of Borneo was forested (Brookfield *et al*. 1995). However, although large-scale exploitation of tropical rainforests commenced in the mid 20th century, the forests of Malaysia have had a much longer history of human disturbance dating back to antiquity (Yamada 1997). The Orang Ulu people have probably inhabited both the interior and coastal areas of the modern boundaries of Sarawak for over five millennia, dating back to Palaeolithic times (Jomo *et al.* 2004). Dunn (1975) suggests that trade in forest products may have occurred as early as 20,000 years BP, with a plank of timber discovered in Peninsula Malaysia dated to 2453 years BP, providing direct evidence of early timber cutting in the region.

Brookfield *et al.* (1995) suggest that some interior regions of Borneo carried a significantly larger human population just 100 to 300 years ago than they do today, including wet-rice cultivation, and evidence that areas that now exist as what appears to be primary forest may have been populated in the past also. However where large concentrations of people are still found, most forest is considered secondary, and Stuebing (2005) suggests that the idea of virgin jungle existing in Sarawak outside of small remote patches is more a romantic ideal than an objective reality. Indeed, as early as the mid 19th century, Low (1848) observed in parts of Sarawak with comparatively high populations, that Iban (the main indigenous people of Sarawak) no longer had "old jungle" in their territories; or if it existed it was at such a distance from their houses that it was not practical to transport its produce. In his 1851 journal, St John (1862) made similar observations during a voyage through the upper parts of the Seribas River, where very little "old-forest" could be observed.

1.2 Sarawak's Forests

The forests of Sarawak (Figure 1.2) can be grouped under eight broad categories: mixed dipterocarp forest (57% of The States land area); peat swamp forest (12%); kerangas or tropical heath forest (3%); mangrove forest (1%); beach/littoral forest (<1%); riverine forest (<1%); montane forest (<1%); and limestone forest (<1%) (Hazebroek and Morshidi 2001) (Figure 1.3), with the remaining land area under industrial timber plantation, oil palm estate, agriculture or other non-forest development. Two forest types of special significance to the development of the forest industry in Sarawak are the mixed dipterocarp forests and the peatswamp forests and are discussed further below.

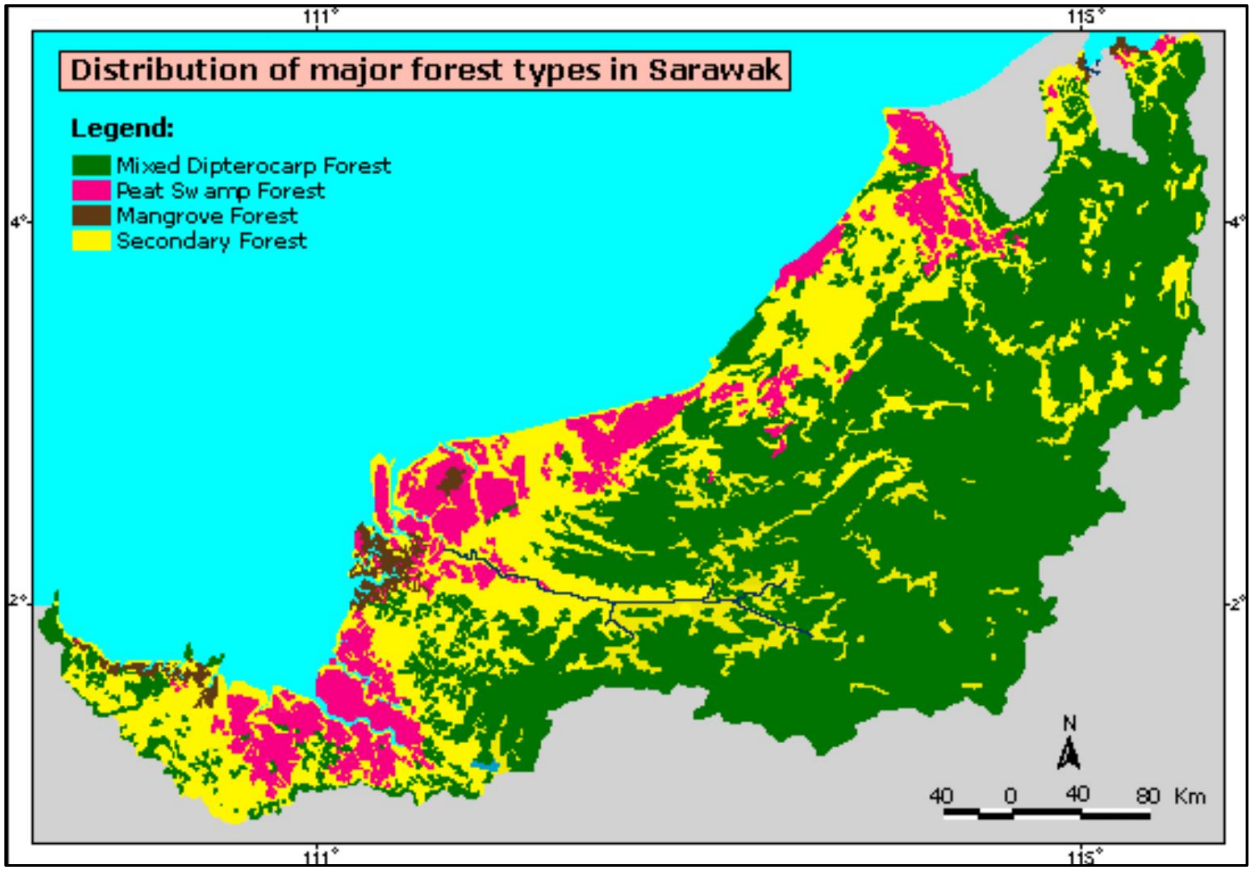

Figure 1.2: Distribution of major forest types in Sarawak. Source Forestry Department, Sarawak: (Source Forestry Department, Sarawak: www.forestry.sarawak.govt.my)

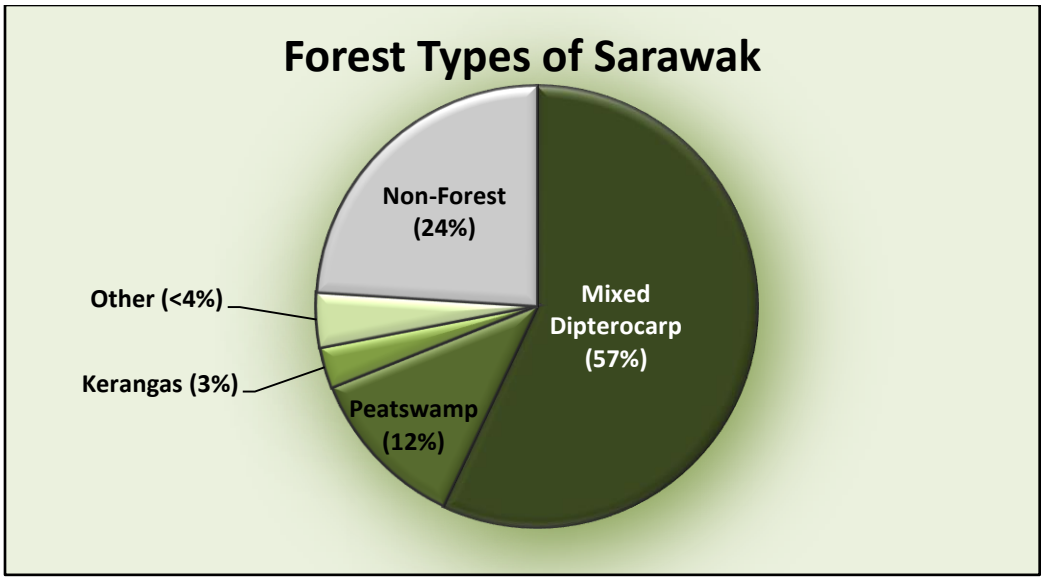

Figure 1.3: Forest cover of Sarawak by land area.

Hill Dipterocarp Forest: Trees of the family *Dipterocarpaceae* are the dominant element of Southeast Asia's tropical rain forests (Schulte 1996). The richest of the forest types is the mixed dipterocarp forest (MDF) which contains more than 2000 tree species and accounts for 57% of the Sarawak's total land area (Hazebroek and Morshidi 2001). The dipterocarp forests of Sarawak are generally richer in commercial timber species than the forests of Africa or South America (Jonkers 2002). Harvesting of Sarawak's hill dipterocarp forests for timber began in 1968 (Tawan 2006), and helicopter logging was subsequently introduced in 1993 as a solution to accessing high quality timber in difficult and otherwise inaccessible terrain (Hui 2002). The hill dipterocarp forests to the south of Bintulu (Figure 1.4), and occupying roughly the area of the current Planted Forest Zone (PFZ) of Sarawak were described by the Food and Agriculture Organisation (FAO) (1972) as being "one of the largest single areas of uncommitted high quality commercially valuable hardwood forest in the world". Following this FAO report, widespread timber harvesting of these forests within the now PFZ area began in the early 1970's (Stuebing 2007).

Primary dipterocarp forests are the most species rich and tallest of the range of forest types, with tree crowns at a height of 25–45 m above ground level and with emergents reaching heights of 60–80 m tall. Beneath the main canopy are two more tiers of trees; sub-canopy trees and treelets respectively, beneath which the ground layer is composed of forest floor herbs and advanced regeneration of future canopy trees (Davies and Kamariah 1999).

Figure 1.4: Hill dipterocarp forest of the Planted Forest Zone (PFZ), Bintulu Division, Sarawak, East Malaysia (Photograph A. Shadbolt, 2009).

Secondary forests; those that have been extensively logged in the past or those recovering from shifting cultivation, are much simpler in structural complexity. These forests typically have fewer emergent trees present, and a reduced canopy height. For example the Samarakan

Conservation Forest; referred to elsewhere as Glen Forest **(**N 02°56.462' E113°07.603') in PFZ, Bintulu Division, Sarawak has a canopy height of 25 m (Ragai and Tuen 2007).

Peat Swamp Forest: Ipor (2006) reports that Sarawak has the largest area of peat land in Malaysia, totaling approximately 1.66 million hectares; 13% of the total land area of the State. As with the mixed dipterocarp forests, the peat swamp forest is one of the most important vegetation types in Sarawak (Tawan 2006), with 255 tree species recorded by Anderson (1972), who earlier recorded 1,706 plant species in total for this forest type (Anderson 1963). The peat swamp forests of Sarawak have been the most heavily exploited of the forest types in The State (Figures 1.5 & 1.6), primarily due their ease of access, yet they remain the least known scientifically (Ipor 2006; Ipor *et al.* 2006; Abang and Hill 2006).

Figure 1.5: Peat swamp forest remnant north of Bintulu, Sarawak, East Malaysia (Photograph A. Shadbolt, 2011).

Figure 1.6: Logged over peat swamp forest north of Bintulu, Sarawak, East Malaysia (Photograph A. Shadbolt, 2011).

Jackson (1968) commented that the under developed countries of the world were embarking on strategies for rapid development, and yet it was precisely in these areas that the least was known about the environmental setting; the exploitation of Sarawak's peat swamp forests being a prime example. Despite being the least known forest type in terms of its biodiversity (Abdullah *et al.* 2006), no intact peat swamp forest remains as a result of exploitation and/or conversion to other land uses (Ipor 2006).

Harvesting of this forest type began on a large scale in 1946, and by 2000 most or all of the peat swamp forests of The State had been logged, with a typical rotation period of 45 years (Tawan 2006). Ramin timber *(Gonystylus spp.)* from peat swamps had been a major component of the Sarawak timber trade since 1948, and in 1970 amounted to 93.25% of the total volume of sawn

timber exports. However by 1972 ramin harvest had reached its peak and production was predicted to decline rapidly (FAO 1972) as a result of overexploitation (Keong 2007), and is now considered threatened over much of its range (Davies and Kamariah 1999). In October 2004, ramin satisfied the biological and trade criteria for listing in Appendix II of the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES) (Chen and Zain 2005) following a proposal from Indonesia to strictly regulate its trade (Keong 2007).

1.3 Forest Land & Forest Policy

The basis of all statute law in Malaysia is the Federal Constitution which lists forestry in Sarawak (and Sabah) as state matters, along with agriculture, native law and custom, land matters, state works and water, and local government (Seng 2007). Therefore the responsibility of regulating forest use in Sarawak lies with the Sarawak State Government, and accordingly the bulk of revenues from timber production are retained by The State (Cooke 1999).

Malaysian forest policies first evolved with the appointment of the first Chief Forest Officer in the early 20th century; a time when expanding rubber plantations and tin mining were putting increasing pressure on the forest resources of the country (Hammond 1997). In 1971 a National Forestry Council (NFC) was set up by the Federal Government as a channel for discussion between the federal and state governments on forestry matters and to co-ordinate a unified approach on such matters[1]. The National Forestry Policy (NFP) was developed as a sectorial policy that aims to maximise social, economic and environmental benefits as a result of sound forest management practices, and has introduced the Permanent Forest Estate (PFE) system of forest-land classification (Oh 2000). Thus forest lands in Sarawak are broadly grouped under

[1] www.forestry.sarawak.govt.my. Sourced 25th September 2010

three categories: Permanent Forest Estate (PFE), Totally Protected Areas (TPA's), and Native Customary Rights (NCR) land.

Permanent Forest Estate: The PFE (Figure 1.7) covers approximately six million hectares[2] and is under the full control of the Sarawak Forest Department. The Forests Ordinance 1958 provides for the establishment of three categories of permanent forest: Forest Reserve, Protected Forest and Communal Forest (Gillis 1988). Forest Reserves are normally productive forest and accordingly provide the primary permanent source of The State's timber supply. The designation of Forest Reserve does however allow for limited rights of local people to utilize forest produce.

Protected forests are those forests in which the people of Sarawak are able to take timber and non-timber forest produce for their own domestic use, and in which they are able to hunt, fish and also graze cattle. Communal Forests are under the control of the community's administration, and comprise areas of convenient woodland that are set aside to provide for the timber and non-timber forest product domestic needs of a specific community

[2] www.forestry.sarawak.govt.my/forweb/ourfor/typefor/tcsf.htm (Sourced 26th October 2011)

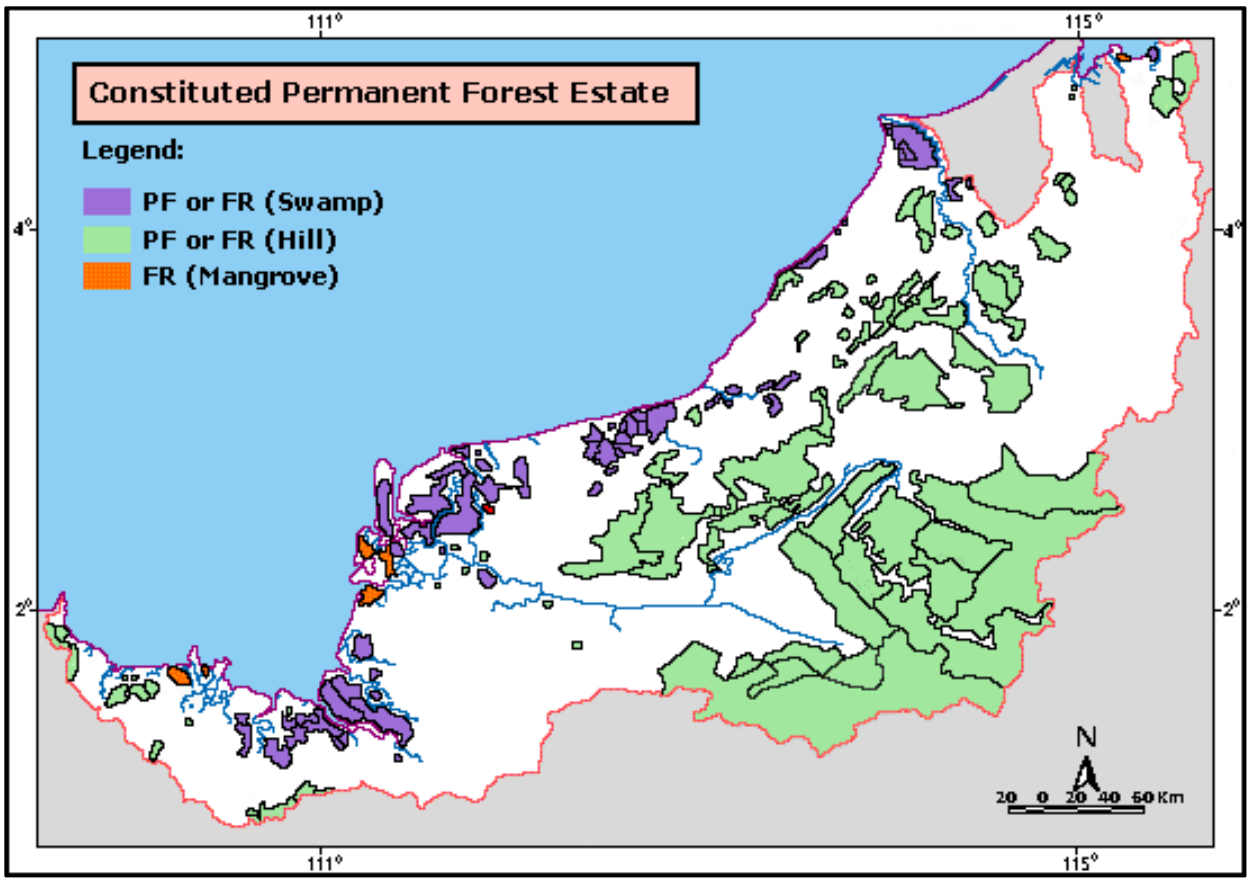

Figure 1.7: Location of Constituted Permanent Forest Estate (PFE) in Sarawak, East Malaysia. PF = Protected Forest; FR = Forest reserve. (Source Forestry Department, Sarawak: www.forestry.sarawak.govt.my)

Totally Protected Areas: In Sarawak, TPA's cover approximately one million hectares[3] and include national parks, nature reserves and wildlife sanctuaries in which logging and other habitat disturbances are prohibited but where legally gazette local communities are afforded limited use rights (Gumal *et al.* 2008). With Sarawak's TPA network is unlikely to exceed ten percent of its total land area (Stuebing 2005) and made up of isolated forest reserves (Figure 1.8), forest and wildlife managers are not able to rely solely on these areas for the protection and conservation of the State's species that they are assumed to cater for. Even by doubling the area of TPA's in Sarawak, the ITTO considered this still to be inadequate to preserve the State's biodiversity (Poore 2003). To this end, National Parks have been described as an outmoded 19th

[3] www.forestry.sarawak.govt.my/forweb/ourfor/typefor/tcsf.htm (Sourced 26th October 2011)

century concept which ignored the fact that forests need to be managed as continuums, and have been condemned as mammalian death traps (Prineas 1998).

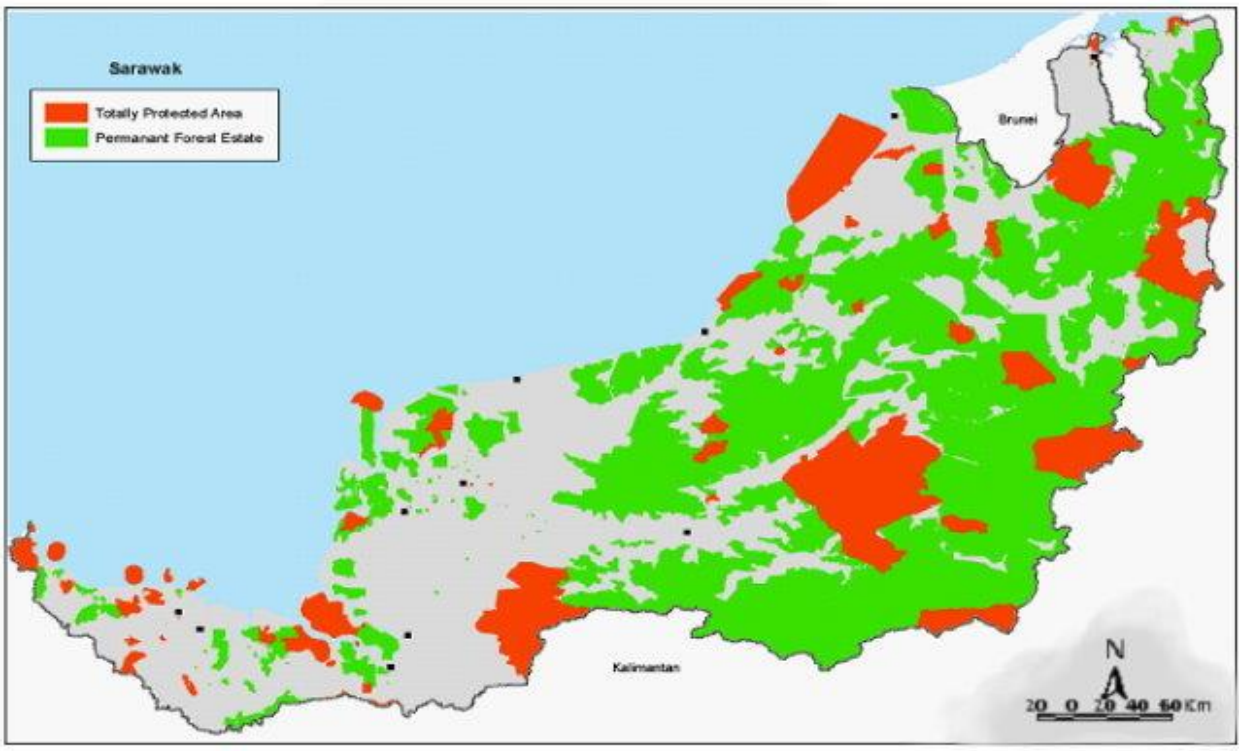

Figure 1.8: Map of Sarawak, East Malaysia showing location of Totally Protected Areas (TPA's) and extent of Permanent Forest Estate (PFE). (Source Forestry Department, Sarawak: www.forestry.sarawak.govt.my)

Furthermore, in addition to the limited use of these forests by local rural communities (Gumal *et al.* 2008), TPA's are by no means immune to other disturbances such as storms, illegal logging, unauthorized shifting cultivation, catastrophic events such as forest fire (Stuebing 2005) and illegal hunting. Fire, as described by Aiken and Leigh (1995), is the oldest of the anthropogenic landscape modifiers. In the second half of 1997, an estimated 45,600 km^2 of forest and vegetation burned in Kalimantan and on the Indonesian island of Sumatra. Although such episodes have been reported since the 1970s, this fire and another in 1994 were considered unprecedented in terms of their extent and intensity (Heil and Goldammer 2001).

Native Customary Rights Land: NCR land covers approximately 20% of State land in Sarawak. Prior to 1st January 1958 any native of Sarawak could claim NCR land by clearing primary forest, however the Sarawak State Land Code 1957 required a permit to be granted, and such permits were seldom granted. Therefore in order to claim rights to NCR land, natives of Sarawak must prove that land has been cultivated prior to 1st January 1958. This has often been a major source of conflict between native communities government, and commercial loggers (World Rainforest Movement 1990).

Family units of most longhouses; a traditional indigenous community structure, can be described as being poor in cash but rich in land, with most occupying between 20 and 40 hectares of land (Forest Department Sarawak, undated). Such an area of forest land is essential in providing timber and non-timber forest resources, and also for the cultivation of hill rice; the staple food of the Iban people, and other subsistence and cash crops. To carry out their subsistence farming, Iban and other native peoples of Sarawak practice shifting cultivation (Aiken and Leigh 1995; Eaton 2005; Forest Department Sarawak, undated); a form of swidden agriculture discussed below.

1.4 Shifting Cultivation

Shifting cultivation is a form of swidden agriculture, and provides a mechanism for rural families to cultivate land which is otherwise unsuitable for the growing of crops (Eaton 2005), and in which the fields themselves rather than the crops are rotated (Aiken and Leigh 1995) (Figure 1.9). In Sarawak, shifting cultivation for the production of hill rice and other food crops has been practiced for centuries (Cramb 1986; Cobb 1988; Freeman, 1955), with Low (1848) reporting Iban using a system of felling secondary forest in order to grow a single years' crop followed by

a seven year fallow period; reportedly a custom of their ancestors. Where population densities are low and land is plentiful enough to allow long fallow periods, it has been argued that shifting cultivation can provide for the restoration of both forest and soil fertility (Eaton 2005).

Figure 1.9: Shifting cultivation near Tubau, Bintulu Division, Sarawak, East Malaysia, showing different stages of cultivation and fallow (Photograph A. Shadbolt, 2010).

However the FAO (1974) reported that even a 15 year rotation cycle may not be sufficiently long enough to restore adequate soil fertility, and based on this estimate, approximately 28 ha is required per family unit for the cultivation of hill rice. Over the past one hundred years shifting cultivation has had a great impact on the landscapes of rural Malaysia (Figure 1.10); particularly in Sabah and Sarawak (Latif and Zakri 1998). By the late 1980s there was already a shortage of land in southwest Sarawak on which to practice traditional forms of agriculture. This land shortage exerted pressure on both the PFE and TPA's to the extent that shifting cultivation encroached into the PFE at a rate of 5000ha per annum, and onto State land at a rate of up to 50,000ha per annum.

Figure 1.10: Large-scale shifting cultivation near Simunjan, Samarahan Division, Sarawak, East Malaysia (Photograph A. Shadbolt, 2008).

The FAO (2002) also reported that shifting cultivation in Sarawak had increased from 2.25 million ha in the 1960's to 3.33 million ha by 1985. Included in this area was an estimated 116,000 ha of the PFE lost to shifting cultivation by 1985, and 1,080,000 ha of interior 'primary forest' cleared for this purpose between the 1960s and 1985 (Poore 2003). Furthermore, the opening up of forests as a result of logging operations further encouraged settlement of, and pressure on, these areas (Jonkers 2002; Eaton 2005). This demand for agricultural land is promoted as one of the major factors contributing to deforestation in the tropics (Evans and Turnbull 2004); the stance usually taken by the often intertwined federal and state governments, and the timber industry (Eaton 2005). Others (E.g. Cobb 1988) contest that this form of

agriculture is little understood in Sarawak, and that 'well managed' shifting cultivation can work in harmony with natural processes rather than against them to preserve soil nutrient levels, reduce run-off and soil erosion, and facilitate natural forest succession.

However over-cultivation by traditional methods of shifting cultivation has been perceived by policy makers in Sarawak as causing widespread land degradation, and underinvestment in more productive and profitable land use (Cramb 1986), and in the 1970s was thus seen as constituting a serious economic development problem (FAO 1974). In light of this, the national governments of both Indonesia and Malaysia have become committed to the elimination of shifting cultivation (Brookfield *et al.* 1995; Potter 2003), and since the mid-1990s large scale social engineering in the form of plantation agriculture has taken place in Sarawak with the aim of redesigning rural life (Cooke 2006).

In their investigation of conflict between commercial logging and shifting cultivation in the Model Forest Management Area (MFMA) south of Bintulu, Pedersen *et al.* (2006) report that while the logging operation was seen to negatively affect hunting, fishing and the gathering of wild products, Iban viewed the operators positively in terms of employment opportunities and assistance with infrastructure. Because of good off-farm employment opportunities in Malaysia, where the opening up of forest lands in other parts of the world are often associated with an influx of settlers, the process has reversed in Sarawak with a reported decline in people living in traditional longhouse communities (Pedersen *et al.* 2006). Similarly in Sabah, although local farmers were strongly opposed to plantation forestry which they saw as a threat to their traditional practice of shifting cultivation, Sabah Forest Industries (SFI) developed a system by which the two potentially conflicting land uses could be incorporated (Awang and Taylor 1993).

1.5 Plantation Forestry in Sarawak

Plantation forestry in the Southeast Asian region dates back to the 19th century (de Jong *et al.* 2003). Although the planting of forest species in Malaysia has been recorded as early as 1880 (FAO 2002), the establishment of large scale exotic timber plantations did not begin in earnest until the mid-1970s (Tsai 1988). One of the first examples from Eastern Malaysia was that of Sabah Softwoods Sdn Bhd in the 1980s; a joint venture between the Sabah Foundation and a large international timber company (Stuebing 2005). However prior to the introduction of rubber in 1905, previous attempts at plantation agriculture in Sarawak, including tea, coffee, tobacco, and sugar cane had met with failure (Aiken and Leigh 1995).

In Sarawak, experimental trials of species with agroforestry potential were conducted early last century to provide a solution to the large areas of forest land that had become degraded through the practice of shifting cultivation. However no major plantings were carried out until 1965, with the initiation of the 'Reforestation Research Programme'. (FAO 2002). Land development programs in Sarawak have historically targeted 'idle' land by promoting the conversion of NCR land to oil palm plantation (Figure 1.11) under joint venture schemes; thus promoting Dayak into mainstream economic development. Such schemes may typically involve a 60% share retained by the company, 30% by the local community(s), while the government acts as a trustee enjoying a 10% share (Cooke 2006). The Sarawak State Government has a target of one million hectares of oil palm plantation in Sarawak by 2010, of which at least 400,000 ha are to be converted from NCR land (Cook 2006).

Figure 1.11: Large scale industrial oil palm plantation estate, Sarawak, East Malaysia (Photograph A. Shadbolt, 2008).

The first *Acacia mangium*; a tropical tree species capable of colonising difficult sites, was introduced to Sabah in 1966 (Awang and Taylor 1993) as a fire break around *Eucalyptus deglupta* and *Gmelina arborea* trees, both of which the acacia out-performed (Pinyopusarerk *et al.* 1993). By the 1980's acacia was being planted on a large scale in both Sabah and Peninsula Malaysia (Wong *et al.* 1998) as the principal species identified for the production of pulp; the planting material of other species proving difficult to procure (FAO 2002).

Where the planting of industrial timber plantations is carried out on alang-alang *(Imperata cylinerica)* grasslands or degraded scrub areas, their establishment can be viewed as a form of re-forestation. However in both Sarawak and Kalimantan alike, often productive forest is cleared to make way for these plantations (Potter 2003) (Photograph 1.12). Therefore the encouragement of tropical plantations carries a significant risk that natural forests will be cleared to facilitate their

establishment; a loss of natural forest and associated biodiversity that may not be recognised by policy makers and/or other stakeholders (ITTO 2007). Indeed the recent interest in large scale estate crops like oil palm is resulting in the clearance of large tracts of rain forest (de Jong *et al.* 2003), and today plantation forestry is seen to be taking over much of the former naturally forested landscape of Borneo (Padoch and Peluso 2003), including the Malaysian states of Sarawak and Sabah.

Figure 1.10: Clearance of secondary forest in Sarawak, East Malaysia, to make way for fast growing industrial timber plantation establishment (Photograph A. Shadbolt 2005).

As a result of logging, shifting cultivation, and conversion to other land uses worldwide, tropical rainforests are disappearing at a rate of 15 million hectares annually (Yamada 1997). The pressure on natural forests to provide timber products to consumers is so high, that many timber companies have converted these forests to managed fast growing timber plantations (Giman *et al.* 2007). Similarly, many countries of the Asia-Pacific region have since turned to plantation

forestry, in response to the diminishing harvesting capacities of their natural forests (Enters *et al.* 2004; Martana 2004; Potter 2003). At 113.2 million hectares, Enters *et al.* (2004) estimate forest plantations to make up or approximately 16 percent of the total forest cover in the Asia-Pacific region; a region accounting for around 61 percent of the worlds plantation forests.

By 1990 the hill forests of Sarawak were being harvested at a rate of 13 million m^3 per annum, which if continued at such a rate it was estimated that this would have seen all primary forests available to timber concessions harvested by about 2001 with only cut-over forests remaining (Poore 2003). Also, at about that time, the 'southern plantation countries' of Australia, New Zealand, Chile and South Africa had begun to capture the market share of wood production from Indonesia and Malaysia who had both exploited their natural advantages throughout the 1970s and 1980s (Enters *et al.* 2004).

In Sarawak, Chan (1998) identified that investors with existing timber processing facilities were faced with the choice of either planting trees (i.e. plantation forestry) to ensure the supply of raw materials to their plants, or to gamble on the sustainable management of the States natural forests. In 1996 the Sarawak Chief Minister Datuk Patinggi Tan Sri Abdul Taib Mahmud stated, "The State has reached its peak in producing timber from natural forests and needed to find better ways to sustain timber resources," and that "the State's timber industry will be better off if it embarked on reforestation with fast growing species to supplement timber production" (Fong 1998).

With approximately 41% of Sarawak's naturally forested land area (3.6 million ha) under Stateland Forests, and much of which was capable of being alienated for the production of cash crops (Appanah and Ali 1998), the late 1990s saw the State Government identify at least one

million hectares available for the establishment of plantation forestry, with the Chief Minister publicly announcing that the State should be planting a minimum of 20% of the Permanent Forest Estate (PFE) as tree plantations (Chan 1998). The Sarawak State Government accordingly made extensive changes to both the Land Code and the Forest Ordinance to allow over 600,000 hectares to be allocated to private plantation companies, and thus restricting customary rights to those lands (Cramb 2007).

The argument has often been put forward that plantation forestry could reduce pressure on natural forests (MacKinnon and Sumardja 2003; FAO 2002; Barber 1998; Ellis 2007); a resource from which the supply of industrial timber predicted to decline in the medium term (Tomaselli 2007). Consequently, with the suggestion that raw material supply to wood based Malaysian industries may soon be derived from the plantation sector (Woon and Norini, 2002), coupled with an increasing demand for wood fibre (Chan, Kho and Lee 1998), particularly in the Chinese and South Korean paper industry (Chemsain Konsultant Sdn. Bhd 2006), planted forests in Sarawak and Sabah are now a major feature of the landscape. As part of this paradigm shift, the Sarawak Forest Department has established a fast growing *A. mangium* plantation in a specially designated 504,000 hectare Planted Forest Zone (PFZ) (Figure 1.13) in the Bintulu Division of the State (Stuebing 2005).

Towards the latter half of last century the forests of the PFZ were regarded as one of the largest remaining single areas of uncommitted high quality and commercially valuable hardwood forests in the world (See FAO 1972; FAO 1973; FAO 1974). Harvesting of these forests began in the early 1970's (Stuebing 2007), and repeated selective harvesting of commercial timber species resulted in a heavily degraded and simplified forest structure with a comparatively low canopy and few emergent trees compared to primary forest. Furthermore, although local indigenous

peoples have practiced shifting cultivation along the main river systems and their tributaries for perhaps hundreds of years, the ingress of new forest road networks allowed shifting cultivators increased access to previously inaccessible forests. This practice of shifting cultivation has also contributed to a mosaic of various aged disturbance patches across the PFZ landscape, adding to the heterogeneity and fragmentation of the natural forest over a range of spatial scales.

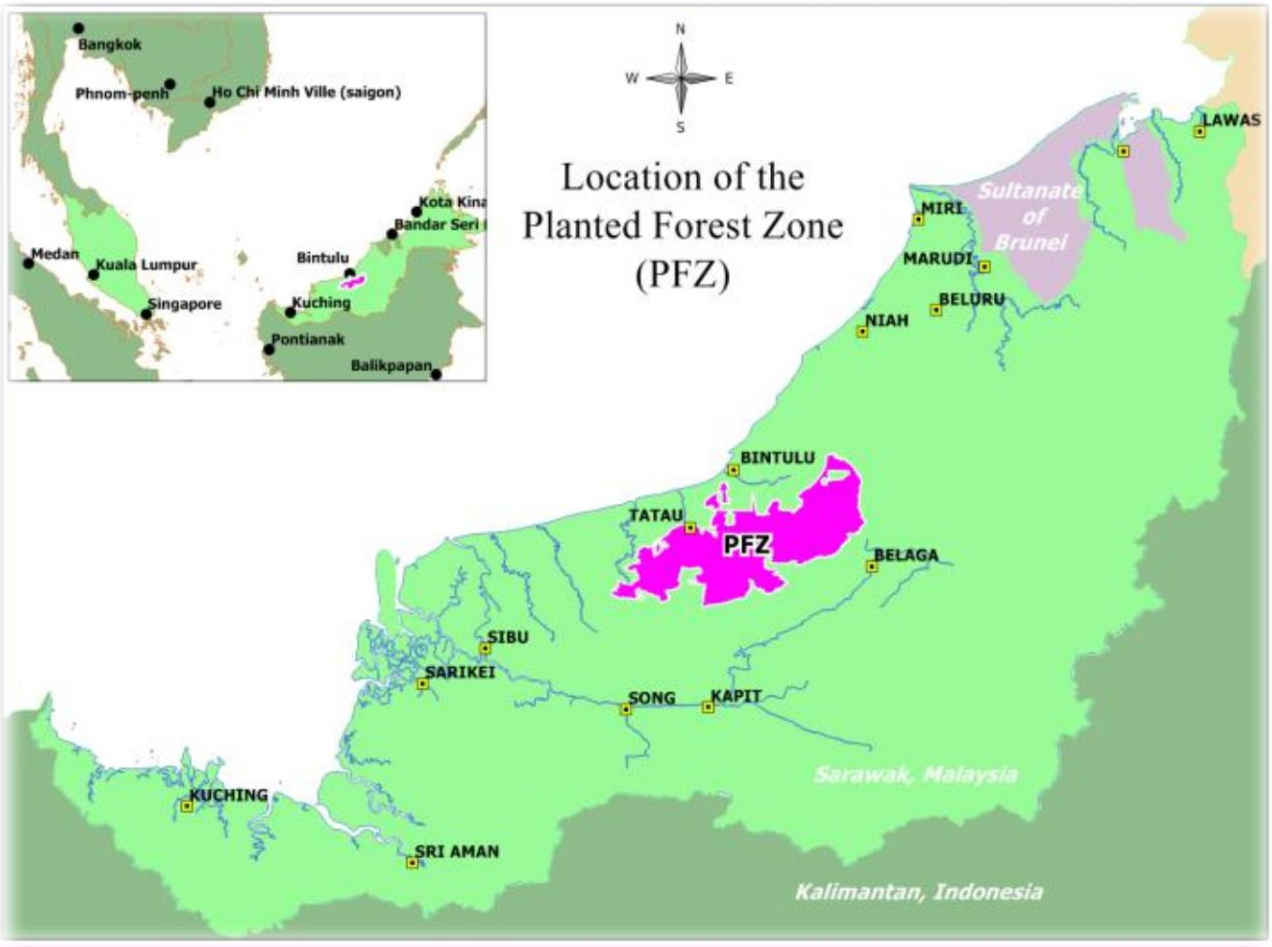

Figure 1.13: Location of Planted Forest Zone (PFZ) in the state of Sarawak, East Malaysia (Source Hall, Undated).

Governments are increasingly handing over rights to forest utilisation along with forest management responsibilities to private operators (Landell-Mills and Ford 1999). In the case of the Planted Forests project in Sarawak however, the project is 100% government funded (Ellis 2007), and the State government has contracted Grand Perfect Sdn. Bhd. (GP); a consortium of

three local timber companies as the primary contractor tasked with the establishment of a the specially designated 504,000 hectare Planted Forest Zone (Stuebing 2005) discussed above. In 2006, the planting of acacia across the PFZ was progressing at a rate of 24,000 ha per annum (Chemsain Konsultant Sdn. Bhd 2006), with the plantation nursery (Figure 1.14) capable of producing approximately three million acacia seedlings per month (Ellis 2007). The pulp produced from the PFZ, at a projected rate of 750,000 tonnes per annum, is expected to cater for both domestic and international needs and is intended to capitalize on the lucrative pulp and paper industry (Chemsain Konsultant Sdn. Bhd 2006). However to put this in context, despite the large scale of such a project, 500,000 ha of acacia would satisfy just 15% of Japans demand for hardwood chips; a demand which is only expected to increase (Glyn 1998).

Figure 1.11: *Acacia mangium* seedling production at the Samarakan Nursery, Planted Forest Zone, Sarawak, East Malaysia. The Samarakan Nursery has capacity to produce 3,000,000 seedlings per month (Photograph A. Shadbolt, 2010).

Meanwhile industries in Kalimantan are also looking to gain a market share in the plantation industry (Potter 2003). In the 1990s the Indonesian government pushed for the establishment of industrial tree plantations in Kalimantan (Colfer and Soedjito 2003; Potter 2003), and Pirard and Cossalter (2006) report applications to build pulp mills in South Kalimantan (600,000 tonne) and Central Kalimantan (250,000 tonne) (Pirard and Cossalter 2006), indicating that the promotion of these plantation areas will be a major feature of the countries forest policies in the near future (Mayer 2003). By 2003, over one million hectares had been allocated for timber plantations in West Kalimantan (Peters 2003). Across the whole of Indonesia, pulpwood plantations account for 42% of the total 2.9 million hectares of established plantation area, and at 68% also dominates the total area 'allocated' to plantations (5.04 million hectares) (Martana 2004).

While it is planned that acacia grown for the supply of pulp will be grown on a rotation of seven to eight years (Figure 1.15), Barber (1988) predicts that lengthening the growing cycle to 12 years not only significantly increases the production of commercial grade wood, but may also substitute the need to harvest from natural hardwood forests. However based on projections from East Kalimantan, Potter (2003) suggests that just two rotations of a fast growing timber species like *A. mangium* is likely to exhaust the poor soils, and have adverse effects on water-flow and soil erosion (MacKinnon and Sumardja 2003).

Figure 1.125: Author with eight year old *Acacia mangium* logs harvested from the Planted Forest Zone, Sarawak, East Malaysia. (Photograph J. Unggang, 2010).

1.6 Sustainable Forest Management

In Sarawak the protection of botanical and wildlife diversity is the responsibility of the Department of Forestry (Latiff and Zakri 1998). The State Government of Sarawak identify that wildlife has major aesthetic and spiritual value. It is therefore regarded as a moral obligation for future generations to be allowed to experience the richness of The State's wild species (Gumal *et al.* 2008).

It is envisaged that large scale planted forests like those of the PFZ have the potential to play an increasingly important role in ensuring that sustainable forest management (SFM) is achieved (ITTO 2007). To this end, the Malaysian Criteria and Indicators for Forest Management

Certification of Forest Plantations (MC&I [Forest Plantations]) was adopted as the standard for certification of forest plantations in Malaysia in November 2008 after its need was first identified by the multi-stakeholder National Steering Committee (NSC) in January 2002 (Malaysian Timber Certification Council 2008). The framework for the MC&I (Forest Plantations) is based on ten underlying principles that are in-turn broadly based on Forest Stewardship Council's (FSC) 'Principles and Criteria for Forest Stewardship' (see Table 1.1).

Table 1.1: Comparison between Malaysian Criteria and Indicators for Forest Management Certification of Forest Plantations (MC&I [Forest Plantations]) and Forest Stewardship Council's (FSC) 'Principles and Criteria for Forest Stewardship'.

	Malaysian Criteria and Indicators for Forest Management Certification of Forest Plantations [MC&I (Forest Plantations)]	**Forest Stewardship Council's (FSC) 'Principles and Criteria for Forest Stewardship'***
1	Compliance with Laws and Principles	Compliance with Laws
2	Tenure and Use Rights and Responsibilities	Tenure and Use Rights to the Land
3	Indigenous Peoples Rights	Respect for Indigenous Peoples Rights
4	Community Relations and Workers Rights	Maintenance or Enhancement of the Social and Economic Well-being of Forest Workers and Local Communities
5	Benefits from the Forest	Sustainable Economic, Environmental and Social Benefits
6	Environmental Impact	Conservation of Biodiversity and Ecosystem Services
7	Management Plan	Management Plan
8	Monitoring and Assessment	Monitoring and Assessment of Economic, Social and Environmental Health
9	Maintenance of High Conservation Forest	Maintenance of High Conservation Value Forests
10	Plantation Development	Plantations Should Reduce Pressure on Natural Forests

** (FSC 2004)*

Under each of the principles of the MC&I (Forest Plantations) are listed a number of criteria which judge whether or not a principle has been fulfilled, and their corresponding indicators and verifiers; the latter often being tailored to location of the forest plantation (IE either Peninsula Malaysia, Sabah or Sarawak) in order to take into account for their regional differences. A number of criteria relate directly to the management and conservation of biodiversity values within plantations. At a high level, Principle 1: *Compliance with Laws and Principles*, the criterion requires that plantation management shall 1) respect all federal and state laws and administrative requirements, 2) ensure that the provisions of all binding international agreements such as the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), International Tropical Timber Agreement (ITTA), and the Convention on Biological Diversity are respected, 3) ensure that forest management areas are protected from illegal harvesting, settlement and other unauthorized activities, and 4) ensure that forest managers demonstrate a long-term commitment to adhere to the principles and criteria.

Other principles that either directly or indirectly relate to biodiversity issues within plantation forests include Principle 5: *Benefits from the Forest;* Principle 6: *Environmental Impact;* Principle 7: *Management Plan;* Principle 8: *Monitoring and Assessment;* Principle 9: *Maintenance of High Conservation Value Forest*, and Principle 10: *Plantation Development.*

Field tests of the draft MC&I (Forest Plantations) were conducted by independent assessor companies and stakeholder representatives in mid 2008 at one site in each of the three geographic areas. In Sarawak, the MC&I (Forest Plantations) was tested on Sarawak Planted Forests Sdn. Bhd. for the Planted Forests of the PFZ, Bintulu Division, from the 22nd to the 25th July that year (Malaysian Timber Certification Council 2008). Therefore the planted forests of the PFZ have already played an important role in the shaping of sustainable forest management

in Malaysia. Furthermore, although the main commercial business of Grand Perfect Sdn. Bhd. is the production of industrial timber, the consortium has a significant investment in public good issues, and as such it operates both a Community Development Department and a Conservation Department (GPCon); the latter to mitigate environmental impacts and maintain long term biodiversity values within the PFZ (Hall *et al.* 2007).

1.7 Conservation in the Planted Forest Zone

In 1928, Eric Mjoberg wrote: "*The ground in a rubber plantation lies bare, with drifts of fading yellow leaves here and there. A strange quiet reigns over the land, where everything is so still in the deathly silence, broken by nothing but a gentle rustle in the terminal leaves. Only some chance slug passes by, meekly gliding along on its slimy belly and feasting on the milky white exudations. We feel a curious sense of oppression as we walk on over this soundless land, where death seems to reign as in some churchyard; the realm of forsaken nature, with thousands and thousands of naked stems standing up in the air. We are passing through a zoological garden where the animals stand in motionless humility"* (Mjoberg 1999).

Similar claims like *"monoculture industrial timber plantations will do little to protect biodiversity"* (MacKinnon and Sumardja 2003), and that *"biodiversity within plantation forests will be extremely low"* (Brookfield *et al.* 1995), while more than likely true in some instances, need to be carefully evaluated in the context of individual plantation design and management regimes. Moreover, with regard to conversion of natural forest to other land uses, these claims need to be considered in-light of the other possible alternative land use scenarios (e.g. intensive agriculture) which would likely have a significantly greater adverse impact on wildlife and wildlife conservation efforts than would well managed plantation forestry.

In terms of maintaining long term biodiversity values across the PFZ, following the clearance of degraded secondary forests for the establishment of plantation forest it is planned that approximately 35% of the landscape will be reserved as strategically located conservation set-asides (Stuebing 2005), although Ellis (2007) reports this proportion to be slightly less at 31%. These set-asides include two large forest reserves, Bukit Sarang and Binyo-Penyilam, encompassing 15,000 ha and 25,000 ha respectively (Piper and Cranbrook 2007), and the 20,000 ha Sungai Mina Wildlife Corridor, all of which are intended to be added to The State's network of Totally Protected Areas (TPA's) (Stuebing 2007). Other conservation areas include river and stream buffers varying in width between 6 m and 500 m, steep land, wetlands, and remnant forest patches embedded within each acacia compartment to act as lifeboats for biodiversity. Thus rather than the PFZ landscape consisting of a monoculture of acacia, a mosaic of acacia, evenly distributed forest patches, wildlife corridors and river buffers (Figures 1.16, 1.17 & 1.18) has the potential to maintain a representative sample of the extant biodiversity across the wider landscape, and complement State-wide biodiversity conservation and management initiatives.

On a finer scale, plantation management practices are in place that attempt to provide a degree of multiple aged and multiple species forest stands through the retention of mature fig *(Ficus spp.)* and the large tree legume, koompassia *(Koompassia spp.)* within acacia blocks (Figure 1.19) (Stuebing 2005). Furthermore, one species of koompassia *(K. excelsa)* is legally protected throughout Sarawak (Hazebroek and Morshidi 2001) due to its value for bee nesting and associated honey resource, making it illegal to remove or damage these trees. Hollow and/or otherwise un-harvestable trees are also retained during plantation establishment and harvest rotations (Stuebing 2005). However the identification of hollow trees during the harvesting

operations associated with plantation establishment is likely to prove difficult, as evidenced by the large numbers of hollow trees harvested for economic gain (Figure 1.20).

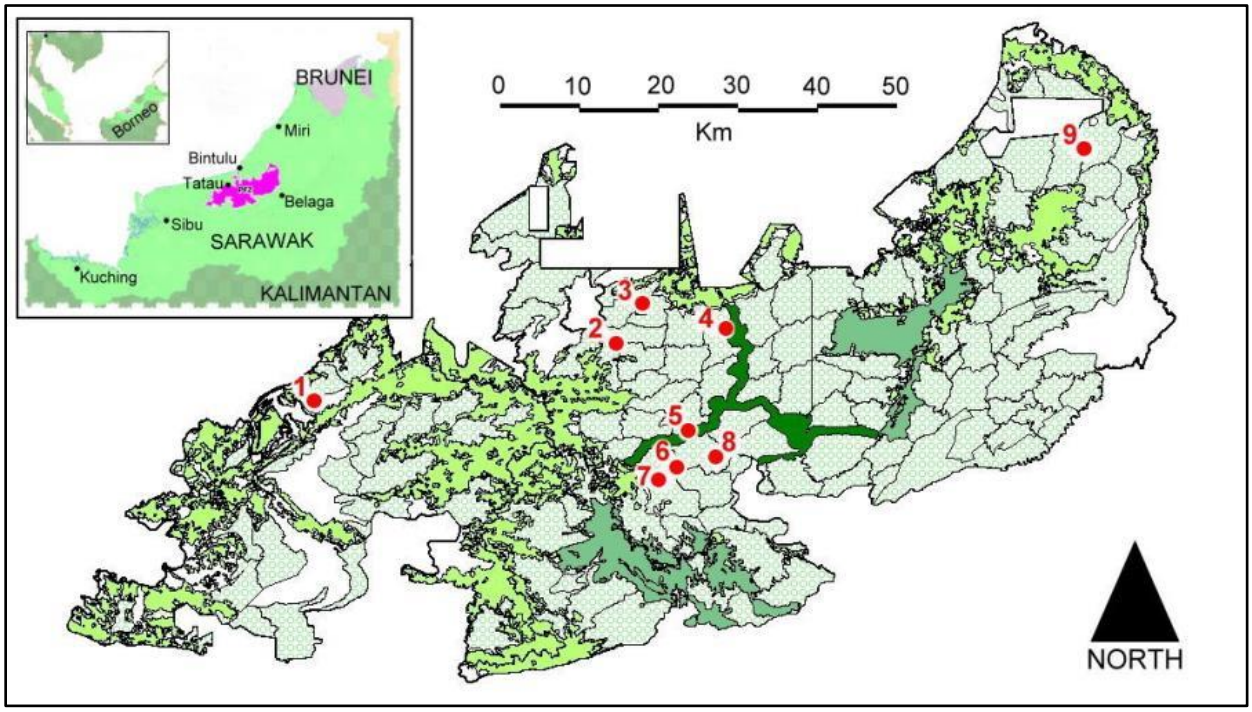

Figure 1.13: Planted Forest Zone (PFZ) showing location of two large conservation areas (medium green), river buffer corridors (dark green), areas of shifting cultivation (light green) and commercial plantation compartments (hatched areas).

Figure 1.14: Small **r**emnant forest patches embedded within acacia compartments in the Planted Forest Zone, Sarawak, East Malaysia, to act as lifeboats for biodiversity. (Photograph A. Shadbolt 2006).

Figure 1.158: Acacia – natural forest mosaic adjacent to the Bukit Mina Conservation Area, Planted Forest Zone, Sarawak, East Malaysia (Photograph A. Shadbolt 2010).

Figure 1.16: Mature ficus tree retained during both plantation establishment and plantation harvest in the Planted Forest Zone, Sarawak, East Malaysia (Photograph A. Shadbolt 2010).

Figure 1.20: Hollow trees felled from areas of cutover forest being cleared for plantation establishment in the Planted Forest Zone, Sarawak, East Malaysia. (Photograph A. Shadbolt 2009).

Average population densities increase linearly from the tropics towards the poles in many faunal groups including mammals, exposing more tropical taxa to threat of habitat change compared to their temperate equivalents (Lawton 1995). Latif and Zakari (1998) report that while no species have been lost in the Malaysian environment, many animal species are nevertheless threatened by habitat loss, hunting, and trapping, to the extent that populations have decreased to limits where they may be no longer able to adapt and persist in the newly transformed environment.

In spite of the degree of habitat loss, modification and fragmentation across the PFZ, and notwithstanding the findings of Gibson *et al.* (2011) in relation to the importance of primary forest in sustaining tropical biodiversity, rather than being an ecological desert the plantation area is shown to be capable of supporting a large proportion of the areas biodiversity (e.g. Demies 2007; Giman *et al.* 2007; Hall *et al.* 2007; Hui and Lim 2007; Kiew *et al.* 2007; Koon 2007; Inger 2007; Lee 2007; Ragai and Tuen 2007; Stuebing 2005; Stuebing 2007; Vermeulen and Junau 2007; Wilson *et al.* 2007). Recent biodiversity inventories carried out by GPCon and its international collaborators have shown that of the local forest vertebrate fauna, 60% was found within acacia aged between four and seven years old, and mirrored the biodiversity of secondary forests (Hall *et al.* 2007). Although the population viability of species occupying acacia stands has yet to be assessed, Stuebing (2005) points out, "there is good reason to believe that long term survival of most species, through understanding of their biology, followed by proper management, will follow". In 2007 the planted forest project was listed as *"one of the six most important scientific experiments in the world"* by Discover Magazine in recognition of its goal of protecting biological diversity and allowing the local community the enjoyment of economic benefits derived from a production landscape (Barone 2007).

1.8 Habitat Fragmentation

In some continuous habitats, all the individuals of a population may live together and interact as a single widespread but discrete population (Forman 1995), however many species have evolved to live in several patches, with very few species naturally occurring in just one area (Spellerberg and Sawyer 1999; Lande and Barrowclough 1987). However threats to the viability of wildlife populations are numerous (Lacy 2000), and when habitats are destroyed, populations residing in these habitats can go extinct and eventually the whole species may do also (Ehrlich 1995). While deforestation can obviously result in the removal of plant species from an area, forest alteration and/or commercial collection are also important endangering processes to a range of biota (Aikan and Leigh 1995). As a result of natural forest conversion to industrial tree plantations, areas of formerly continuous forests are fragmented into smaller patches; a process that is believed to have a great impact on wildlife species and populations (Latiff and Zakri 1998). To this end, the processes of habitat loss and fragmentation are thought to be the primary causes of the extinction of populations, metapopulations (discussed below) and species worldwide (Gu *et al.* 2002)

The process of fragmentation typically results in a landscape-level mosaic of small and large patches of primary forest, variously degraded forest, and completely degraded and transformed ecosystems (Davies 1998), analogous with the landscape of the PFZ. Through human induced habitat loss, modification and fragmentation, biological communities are becoming smaller and smaller, often leading to the isolation of populations (Spellerberg and Sawyer 1999; Davies 1998). In extreme cases of patchiness, suitable habitat can be so widely spaced that no movement or interaction between populations occurs between the patches at all, and thus exist as several discrete populations (Forman 1995). However where these sub populations (demes) are

connected by the movements or gene flow, extinction and re-colonisation events, metapopulations; (populations of populations) arise (Hilty *et al.* 2006; Lande and Barrowclough 1987; Merriam 1991).

The effects of forest fragmentation have been widely reported in the literature for birds (Newmark 1991; Fuhlendorf *et al.* 2002; Kurosawa and Askins 2003; Lampila *et al.* 2005; van Houtan *et al.* 2006), mammals (Verboom and Apeldoorn 1990; Gaines *et al.* 1997; Zollner 2000; Bakker and van Vuren 2004; Strevens 2007; Lees and Peres 2008; Mortelliti *et al.* 2009; Mortelliti and Boitani 2008; Holland and Bennett 2009; Shadbolt and Ragai 2010; Charles and Ang 2010), trees (Cordeiro and Howe 2003; Tabarelli *et al.* 2004), insects (Dunley *et al.* 2009) and for a range of other ecological processes (Chiarello 2000; Hobbs 2001; Hoffmeister *et al.* 2005; Goosem 2007; Gould *et al.* 2008; Jaquiery *et al.* 2008) to name but a few. Small isolated populations, for example those likely to occur throughout the PFZ landscape, and those that require large areas of continuous habitat face additional threats to stability and persistence (Lacy 2000), and are more prone to extinction through proximate causes: 1) demographic stochasticity, 2) environmental stochasticity, 3) genetic deterioration and 4) social dysfunction (Lawton 1995) than are larger populations. Catastrophes; events that occur at random intervals, are also predicted to kill a percentage of the population outright. These events include fires, floods, extreme storm events and droughts (Hunter 1996), extraterrestrial impacts, large earthquakes, tsunamis and volcanic eruptions (Corlett 2009).

Demographic stochasticity is the uncertainty resulting from random variations in reproductive success and survival, immigration and emigration at the level of the individual (Hunter 1996). It can lead to the demographic structure of a population being radically altered (Hilty *et al.* 2006), and is recognised as a potential threat to small populations (Lacy 2000; Lindenmayer and

Franklin 2000; Strevens 2007). Environmental stochasticity; the uncertainty due to random variation in a range of parameters that measure habitat quality, also threatens small populations. This can include such qualities as provision of protective cover, availability of water, relationships with other species including parasites, pathogens predators, prey or competitors, levels of nutrients and pollutants in the environment, and climatic variables (Hunter 1996).

Genetic stochasticity refers to the random variation of gene frequencies occurring within a population that result from genetic drift, population bottlenecks and inbreeding (Hunter 1996). Lacy (2000) illustrates that in theory, populations with less than 50 breeding adults may suffer from inbreeding depression within a few generations, even much larger populations that have been fragmented into isolated sub-populations of fewer than 50 breeding animals each, may theoretically lose variability at a much faster rate than would be estimated from the total metapopulation. However while it is assumed that species that have passed through population bottlenecks should suffer genetic problems as a result of the deleterious effects of inbreeding, there are examples of where species have passed through such bottlenecks and have since begun to establish stable populations. In New Zealand the black robin *(Petroica traverse)* (Freeman 1994), kakapo *(Strigops habroptilus)* (Balance 2010) and takahe *(Notornis mantelli)* are examples, however all have, and are likely to continue to require intensive human intervention in order to secure their long term viability.

Many species are shown to exhibit a metapopulation structure whereby stochastic extinctions are common but are balanced with recolonisations from neighbouring patches, thus allowing the species to persist (Ehrlich 1995). A metapopulation structure may therefore be the only mechanism by which a species' persistence can be assured for a defined period of time (Shaffer 1987) in a patchy landscape, and dispersal amongst patches in a metapopulation is therefore of

central significance, and is likely to be critical to the long term persistence of a species (Hilty *et al.* 2006).

Reasons for dispersal from the natal territory include the avoidance of inbreeding and competition for prospective mates where losers may find it advantageous to move away from a superior competitor (Alcock 1993). However moving about in a landscape is likely to be costly in terms of energy expended (Alcock 1993), and the mobility of vertebrate species invariably brings them into contact with a wide range of environments, objects (Pough et al. 1989) and predators (Alcock 1993) and other threats. Conditions within the matrix can therefore greatly influence the movement of individuals and thus also the connectivity between habitat patches (Lindenmayer and Franklin 2000). However likewise, the internal conditions of forest fragments may be as, if not more important, than their spatial configuration in the landscape in terms of determining their biotic abundance and distribution, and their corresponding value for conservation purposes (Hobbs 2001).

In multi-species metapopulations it is believed that superior competitors exclude inferior species from co-occupied patches, but that inferior competitors are able to maintain their populations as a result of higher rates of re-colonization and lower patch mortality rates (May *et al.* 1995). However as the number of habitat patches occupied by a species diminishes, so too does the probability of vacant patches being recolonised, to a point where regional, potentially global extinctions can occur (Ehrlich 1995). Logically therefore, a species will become extinct at that point in time when the last local population becomes extinct (Lawton 1995), and the point at which a population becomes functionally extinct will be the point at which the population no longer has individuals of both sexes that are capable of reproduction (Miller and Lacy 2003).

1.9 Conclusion

With Sarawak's natural forest resources diminishing, plantation forestry and oil palm estates look set to become permanent features of the landscape. Large scale fast growing industrial timber plantations provide an opportunity to provide for economic growth, community development and conservation of biological diversity on a broad landscape scale. It is therefore hoped that the Planted Forest Zone, if well managed, will provide suitable habitat that is capable of supporting viable populations of a wide range of indigenous flora and fauna. In doing so the plantation landscape will provide a significant extension of The State's Totally Protected Area network, which is currently under considerable pressure in terms of its area restriction, isolated nature of its component reserves, illegal logging, poaching, shifting cultivation, fire and storm damage, species decline and local extinctions. Therefore, although authors (E.g. Barthlott *et al.* 2001; Floren and Linsenmair 2005; Gibson *et al.* 2011; Heinen 1992; Kessler *et al.* 2005; Turner *et al.* 1997; Vulinec 2006) highlight the irreplaceable attributes of primary forest for the conservation of biodiversity, managed plantation landscapes can provide complementary habitat; sometimes the only habitat available for a broad range of species in some areas. However in order to achieve this goal the landscape of the PFZ will need to be managed in such a way that the viability of wildlife populations is secured in the long term.

For many wildlife species that are dependent on natural forest for their persistence, the fragmented state of the remaining natural forest patches in the PFZ will mean that they are isolated within relatively small habitats. In the absence of an ability of these species to disperse between patches, their populations are likely to remain precariously small and prone to local extinction. With the extinction of successive isolated populations, in time this could result in the area-wide extinction of species that are shown to be intolerant of fragmentation.

However with good management and multi-scaled spatially based landscape planning it is anticipated that a landscape mosaic composed of continuous acacia plantation compartments connecting conservation set-asides (wildlife corridors, stream buffers, steep land, remnant patches), and the preservation of fine scale landscape features (standing deadwood, decay cavities, downed woody debris, mixed age compartments) will mean that a representative sample of the areas original biodiversity, with the likely exception of some larger species, will be able to persist as a metpopulation; a series of semi isolated populations (demes) that become extinct and are re-populated following dispersal and emigration from a neighbouring patch.

In this respect, a metapopulation model for wildlife species across the PFZ can be seen as a mechanism for managing and maintaining viable wildlife populations. However a species' viability is likely to be strongly dependant on the ability of individuals to move through the fragmented landscape to re-colonise vacant patches with all the threats that such a journey would entail. The following chapters therefore deal explicitly with the behaviour of wildlife; in this case, non-volant (non-flying) small mammals, that occur across the PFZ. In particular it addresses what these behaviours may mean for their ability to cope with habitat fragmentation, and in-turn their ability to persist as long term viable populations in the plantation landscape mosaics of Sarawak, and the wider tropics.

CHAPTER 2

Non-volant Small Mammal Populations across a Range of Patch Sizes in an Industrial Timber Plantation in Sarawak, East Malaysia

Abstract

Non-volant small mammal trapping was undertaken in the Planted Forest Zone (PFZ) of Sarawak, East Malaysia; a black wattle (Acacia mangium) *dominated plantation landscape characterised by a high degree of habitat fragmentation. Findings from this study revealed no correlation between abundance and patch size for most species except for the brown spiny rat* (Maxomys rajah) *where abundance was found to positively correlated with patch size. Medium sized patches exhibited the greatest species richness and abundance, and the largest forest areas provided the highest trap catch index for the brown spiny rat; a species that is identified as vulnerable across its natural range. Small forest patches of c.1.00 ha that had been exempt from clearing during plantation establishment are likely to be species poor and host small populations of extant species only. The protection and maintenance of forest patches larger than c.5.00 ha may be important in the persistence of non-volant small mammals across the PFZ landscape given that this sized patch hosted as many species as did the largest forest patch (<500 ha), albeit at much lesser abundance. Where multiple trapping inventories were carried out at the same site over consecutive years, both species richness and abundance were observed to fluctuate significantly, illustrating that wildlife populations change over both space and time. Thus the shortcomings of a single trapping inventory performed at a given site are exposed, and are representative of a single snapshot in time only.*

Key Words: *Tupaia longipes, Tupaia picta, Tupaia tana, Maxomys rajah, Sundamys mulleri, Leopoldamys sabanus, Lariscus insignis, Acacia mangium*, fragmentation, Planted Forest Zone, conservation.

Title Page Image: Pen-tailed treeshrew *(Ptilocercus lowii)* trapped at the Samarakan Conservation Forest, Planted Forest Zone, Bintulu Division, Sarawak, East Malaysia (Photograph A. Shadbolt 2006).

2.1 Introduction

A conservation management plan for the Planted Forest Zone (PFZ), Sarawak, East Malaysia (Refer Chapter 1) has identified several groups of abundant, diverse and widely distributed wildlife groups that could be selected for long term monitoring. These include macro invertebrates, herpetofauna, freshwater fish, birds, large mammals and small mammals (Hall *et al.* 2007). To-date, biodiversity monitoring across the range of ecosystems and habitats occurring in the PFZ has illustrated that the modified landscape is capable of supporting a surprising sample of the areas original biodiversity, as illustrated in Demies (2007) (flora); Giman *et al.* (2007) (small carnivores); Hall *et al.* (2007); Hui and Lim (2007) (freshwater fish); Kiew *et al.* (2007) (flora); Koon (2007) (avifauna); Inger (2007) (amphibians); Lee (2007) (Nepenthes); Ragai and Tuen (2007) (small mammals); Stuebing (2007); Vermeulen and Junau (2007) (snails); Wilson *et al.* (2007) (small mammals).

Small mammal research was reported by Louis *et al.* (1988) as being among the least favoured subject of zoologists and wildlife ecologists, and to-date much research has focussed on temperate species (Barnett and Dutton 1995), and more recently in the neo-tropics (E.g. Turner 1996; Voss and Emmons 1996; Gascon *et al.* 1999; Brito and de Souza 2003; Umetsu and Pardini 2005; Passamani and Ribeiro 2009; Mena and Medellin 2010; Rocha *et al.* 2011). Small mammals are generally considered to be those non-volant (non-flying) mammals whose weight does not exceed one kilogram when adult; 63.20% of all terrestrial mammals and 47.75% of all mammals (Barnett and Dutton 1995). They are an animal group that are commonly used as indicators of ecosystem health, and biodiversity surveys provide a fundamental means of determining their diversity and distribution (Wilson *et al.* 2007; Ragai and Tuen 2007). The

population dynamics of small mammal communities are therefore of great interest to ecologists (Nakagawa *et al.* 2007).

Small mammals are frequently used as an indicator group to assess the integrity of a site (Liu *et al.* 2008; Mohammadi 2010), and with their good reproduction rates and colonisation potential, provide an ideal group with which to perform assessments of environmental quality (Slábová *et al.* undated). As many species of wildlife rely on the same habitat elements and structures as small mammals, by studying this animal group we are able to gain a better understanding of the attributes of other species for which it may be too difficult, inconvenient or expensive to collect and interpret robust empirical data (Mohammadi 2010).

Forest fragments are a relatively new feature to Tropical East Asia (Corlett 2009) and particularly to the Island of Borneo. The effects of forest fragmentation have been widely reported in the literature for mammals (Bakker and van Vuren 2004; Charles and Ang 2010; Gaines *et al.* 1997; Holland and Bennett 2009; Lees and Peres 2008; Lindenmayer 2009; Mortelliti et al. 2008; Mortelliti and Boitani 2008; Shadbolt and Ragai 2010; Strevens 2007; Verboom and Apeldoorn 1990; Zollner 2000). However little is known about the species assemblages and community structure of small mammals in tree plantations incorporating a mosaic of both natural and managed exotic forest habitats in Sarawak (Ragai and Tuen 2007).

Populations will not occupy all available sites at any one given point in time and densities vary widely from place to place/year to year (Barnett and Dutton 1995; Cranbrook and Piper 2007; Hall *et al.* 2007). The retention of small forest remnants within the acacia matrix of the PFZ is likely to have enabled the survival of local endemic and indigenous species that would otherwise

have been lost during plantation establishment (See Corlett 2009; Lindenmayer 2009; Lindenmayer and Pope 2000).

Stuebing (2007) identifies one of the future challenges for the conservation of biodiversity in the PFZ will be an ability to maintain reliable long-term records that can be used to direct the appropriate management path for specific species or biological community. In this paper the results from 14 small mammal trapping sessions in ten forest patches ranging from 1 ha to >500 ha, and embedded within the fast growing black wattle *(Acacia mangium)* plantation of the PFZ are reported. All trapping sessions were primarily designed to collect animals for radio telemetry and spool-and-line tracking studies (see Chapters 3 and 4), and while the application of different trapping protocols between trapping sessions do not allow for measures of species diversity (E.g. Simpsons Diversity Index) to be calculated, the results of this study can be used to determine preliminary correlations between patch size and species abundance and richness. The findings from this study can therefore help illustrate the relative merits of conserving a range of forest patch sizes across the managed PFZ landscape.

2.2 Methods

Study Sites: The study was conducted at ten sites in the PFZ (Figure 2.1) situated between longitude 113°00' and 113°15' East and latitude 3°15' and 3°00' North in the Bintulu Division, Sarawak, East Malaysia during five field sessions between June 2006 and July 2010. The study area ranged in elevation from 30 to 80m above sea level and consisted of a secondary mixed dipterocarp and kerangas (heath forest) mosaic in the process of being converted to a fast growing *A. mangium* plantation.

The climate in Sarawak is characterised by uniformly high temperatures ranging from around 22^{o}C before dawn to around 32^{o}C in the early afternoon with a relative humidity well above 90% and around 60% respectively at sea level. Rainfall is spread throughout the year with no distinct dry season, although it does experience two relatively wetter seasons; the northeast monsoon and the southwest monsoon. The northeast monsoon occurs from November to March and brings the heaviest rainfall to the State, and the southwest monsoon occurs from June to September. Rainfall is strongly dictated by topography and thus ranges from less than 2000 mm to >7000 mm per annum (Hazebroek and Morshidi 2001).

The ten forest patches ranged from approximately one hectare in area to over 500 hectares (Mean 158.00 ha). These were: Kakus Forest East, Kakus Forest West (Figure 2.2), Kalabat (Figure 2.3), Kapur One, Kapur Two (Figure 2.4), Kelawit, Lana Road Patch (Figure 2.5); Samarakan Conservation Forest (Figure 2.6), Sungai Mina Conservation Corridor (Figure 2.7), and Tubau (Figure 2.8). The geographic coordinates of the ten forest patches are listed in Table 2.1 along with the dates of the fieldwork sessions.

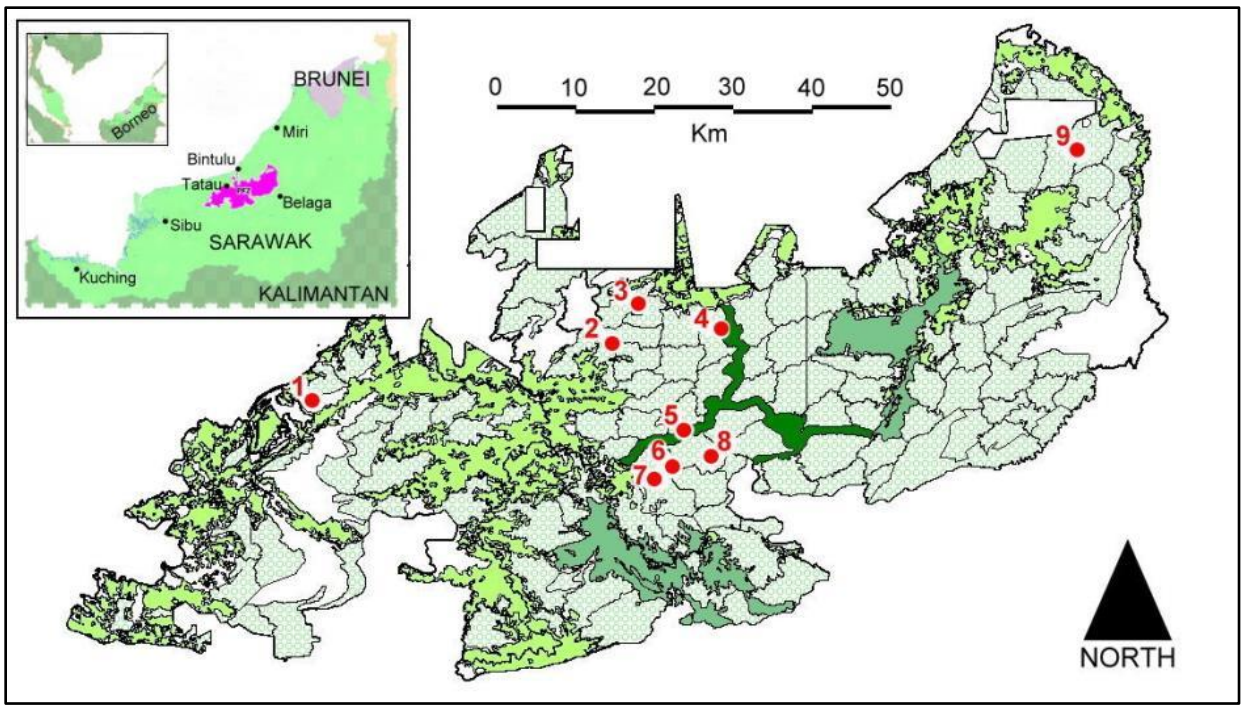

Figure 2.1: Map of the Planted Forest Zone (PFZ), Sarawak, East Malaysia, showing location of the ten small mammal trapping sites: 1) Kelawit, 2) Lana Road, 3) Samarakan Conservation Forest, 4) Kalabat, 5) Sungai Mina, 6) Kapur Patch One, 7) Kapur Patch Two, 8) Kakus Nursery Forest East & West, and 9) Tubau.

One trapping session was conducted at each of the forest patches except for the Samarakan Conservation Forest; referred to elsewhere as *'Glen Forest'* (Wilson and Helgen 2005; Ragai and Tuen 2007; Shadbolt and Ragai 2010). Here trapping sessions were conducted in 2006, 2007, 2008 and twice in 2010 (Refer Table 2.1). Furthermore trapping in the Samarakan Conservation Forest was also conducted by Wilson and Helgen (2005), and the results of their session will be used again here for discussion purposes only.

Apart from their relative sizes, all patches in which trapping was carried out were similar in that all were lowland dipterocarp forest that had previously been subject to selective timber extraction. As a result, all patches were characterised by an internal patchiness of a relatively open under-storey interspersed with dense fern and sapling re-growth in canopy gaps, prolific

downed large diameter woody debris, tree stumps, abandoned haul trails and a general absence of large trees with diameters exceeding 100 cm.

Table 2.1: Geographic coordinates and dates of fieldwork carried out at ten study sites within the Planted Forest Zone, Sarawak, East Malaysia (in chronological order).

Study Site	Coordinates	Dates
Samarakan Conservation Forest	N 02°56'23.97" E 113°07'22.60"	8th Jul - 18th Jul 2006
Sungai Mina Conservation Corridor	N 02°47'29.47" E 113°10'52.27"	23rd Jul – 4th Aug 2006
Kalabat	N 02°54'50.27" E 113°13'34.48"	18th Jun – 30th Jun 2007
Samarakan Conservation Forest	N 02°56'23.97" E 113°07'22.60"	4th Jul – 14th Jul 2007
Tubau	N 03°08'12.35" E 113°38'42.65	18th Jul – 28th Jul 2007
Kelawit	N 02°54'06.55" E 112°47'06.26"	2nd Aug – 12th Aug 2007
Samarakan Conservation Forest	N 02°56'23.97" E 113°07'22.60"	22nd Oct – 6th Nov 2008
Kakus Forest East	N 02°46'02.00" E 113°13'59.90"	25th Jul – 5th Aug 2009
Kakus Forest West	N 02°46'55.30" E 113°13'06.90"	26th Jul – 5th Aug 2009
Kapur One	N 02°45'35.1" E 113°10'45.50"	7th Aug – 17th Aug 2009
Kapur Two	N 02°44'58.40" E 113°10'29.60"	11th Aug – 21st Aug 2009
Samarakan Conservation Forest	N 02°56'23.97" E 113°07'22.60"	20th Jun – 30th Jun 2010
Lana Road	N 02°53'52.83" E 113°05'50.89"	5th Jul – 15th Jul 2010
Samarakan Conservation Forest	**N 02°56'23.97" E 113°07'22.60"**	**5th Jul – 18th Jul 2010**

With the exception of the 2008 trapping session, all trapping was carried out between the months of June and August. Therefore with the exception of 2008, any seasonal bias between trapping sessions was considered to be controlled for. No mast fruiting of dipterocarp trees was recorded during any of the field sessions. Had this occurred it may have resulted in a measuring bias on account of the likely reduced trapability of animals where alternative ample food sources were available. However no data were available on recent mast events in or near the respective forest patches.

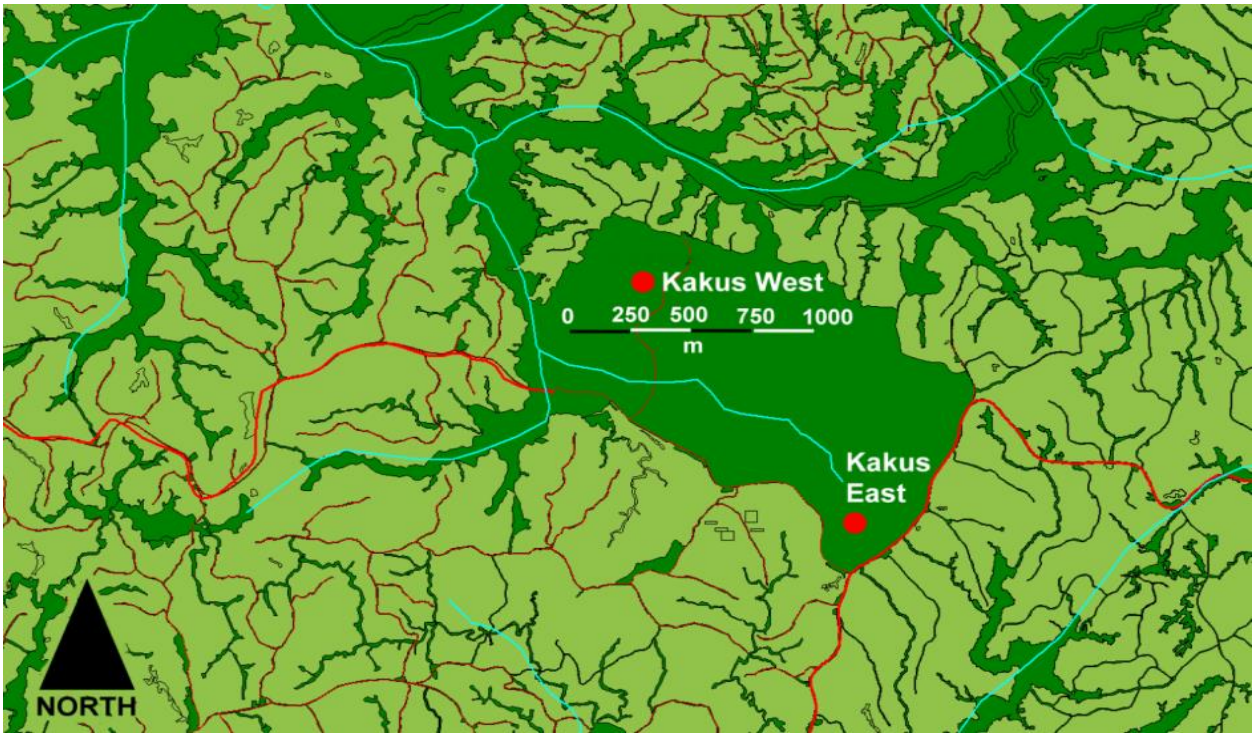

Figure 2.17: Map showing location of two trapping grids; Kakus East and Kakus West, in the Kakus Nursery Forest, Planted Forest Zone, Sarawak, East Malaysia. (dark green = secondary forest; light green = plantation compartments; red lines = forest road networks; blue lines = waterways).

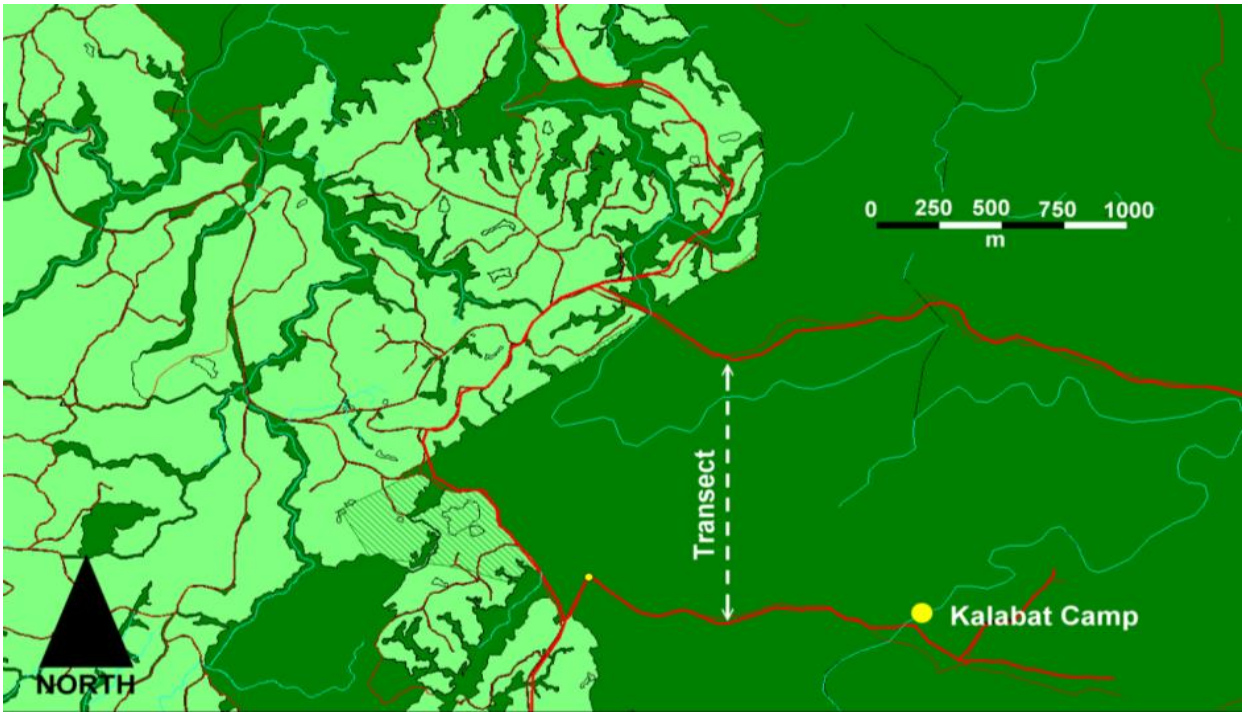

Figure 2.3: Map showing location of the Kalabat Forest trapping transect, Planted Forest Zone, Sarawak, East Malaysia. (dark green = secondary forest; light green = plantation compartments; red lines = forest road networks; blue lines = waterways)

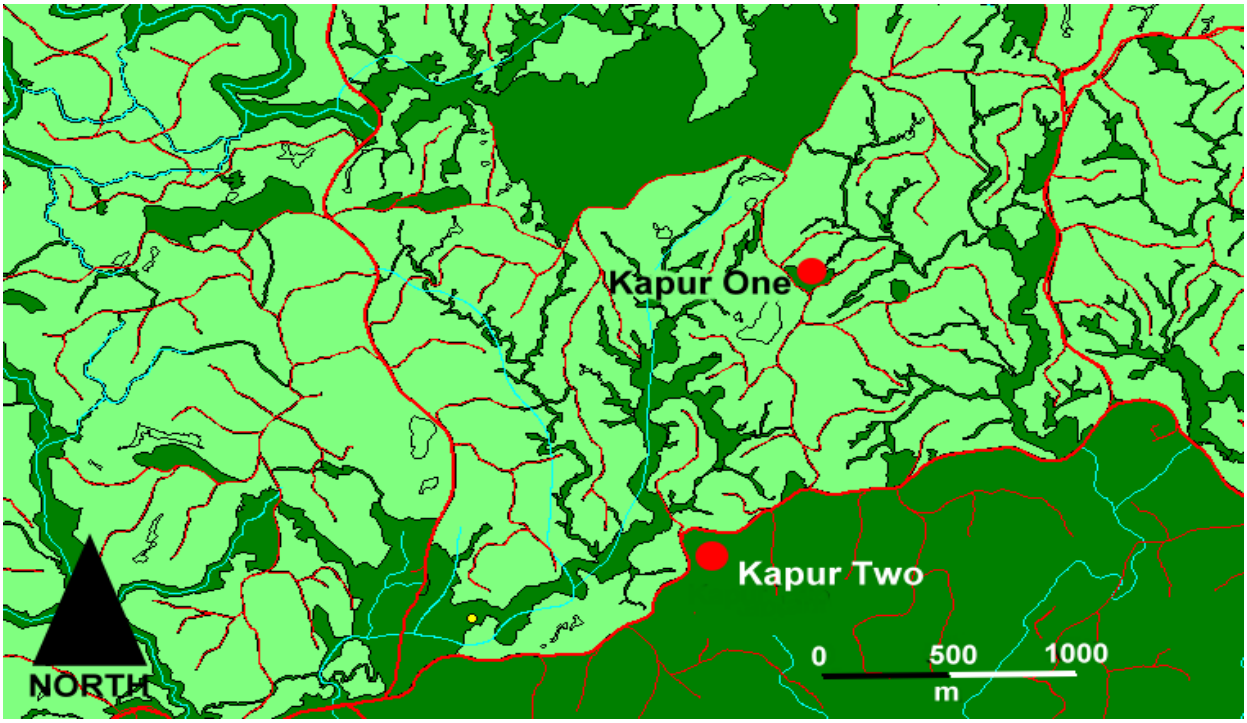

Figure 2.4 Map showing location of Kapur Patch One and Kapur Patch Two trapping grids, Planted Forest Zone, Sarawak, East Malaysia. Note that map indicates location only for the Kapur Two patch as no mapping data is currently available showing post plantation establishment/patch isolation forest types. (dark green = secondary forest; light green = plantation compartments; red lines = forest road networks; blue lines = waterways).

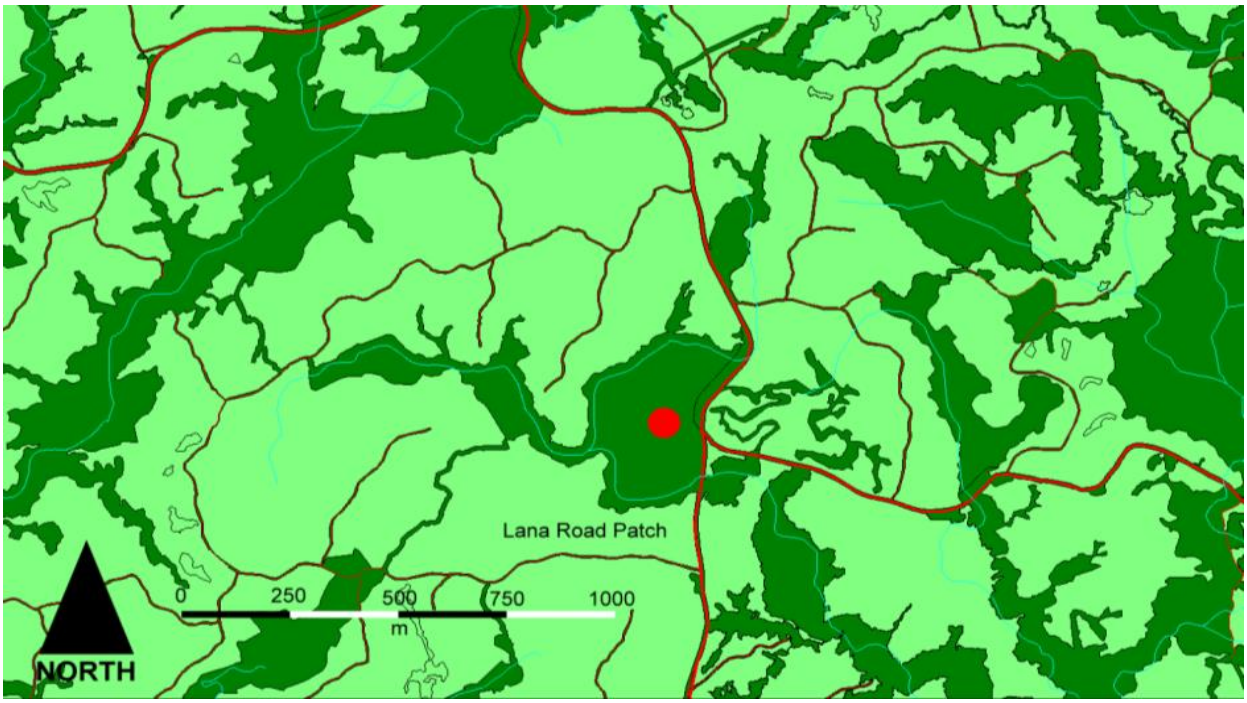

Figure 2.5: Map showing location of the Lana Road Forest Patch, Planted Forest Zone, Sarawak, East Malaysia. (dark green = secondary forest; light green = plantation compartments; red lines = forest road networks; blue lines = waterways)

Figure 2.6: Samarakan Conservation Forest (dashed outline), with Samarakan nursery complex in foreground, Planted Forest Zone, Sarawak, East Malaysia (Map not available; Photograph GP Conservation, 2008).

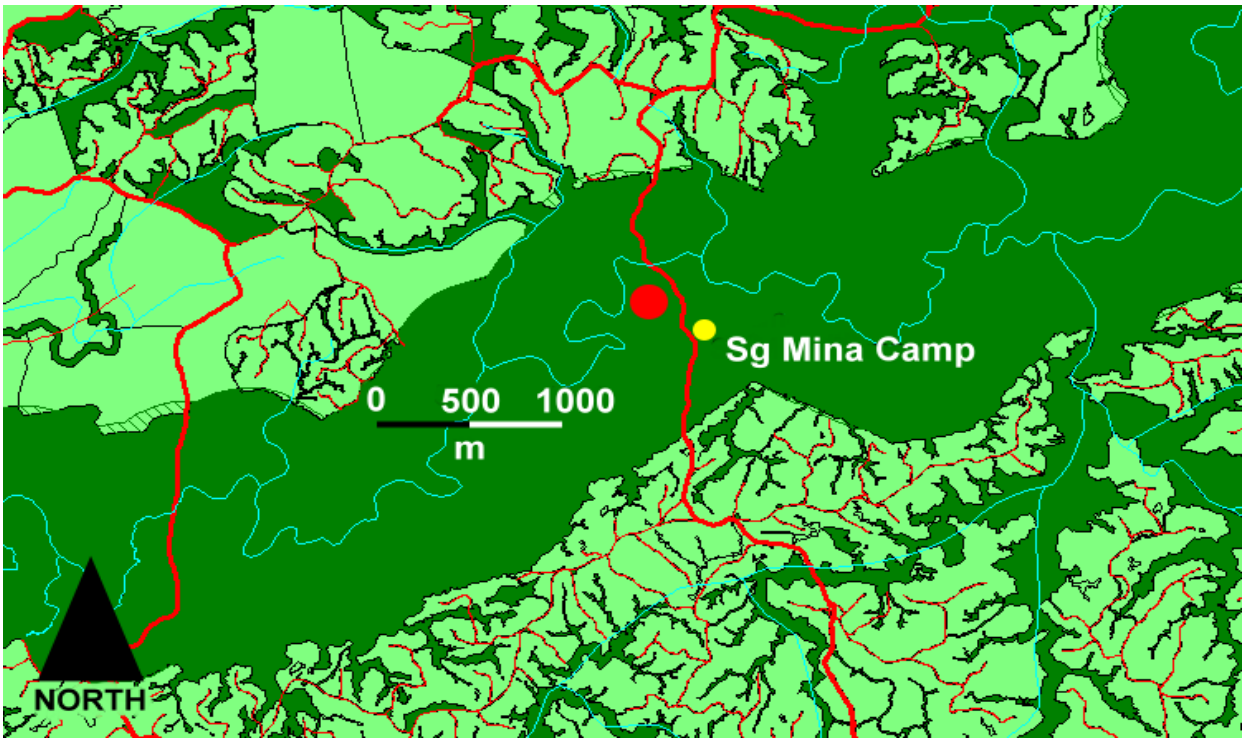

Figure 2.7: Map showing location of the Sungai Mina Trapping Transect (red dot), Planted Forest Zone, Sarawak, East Malaysia. (dark green = secondary forest; light green = plantation compartments; red lines = forest road networks; blue lines = waterways)

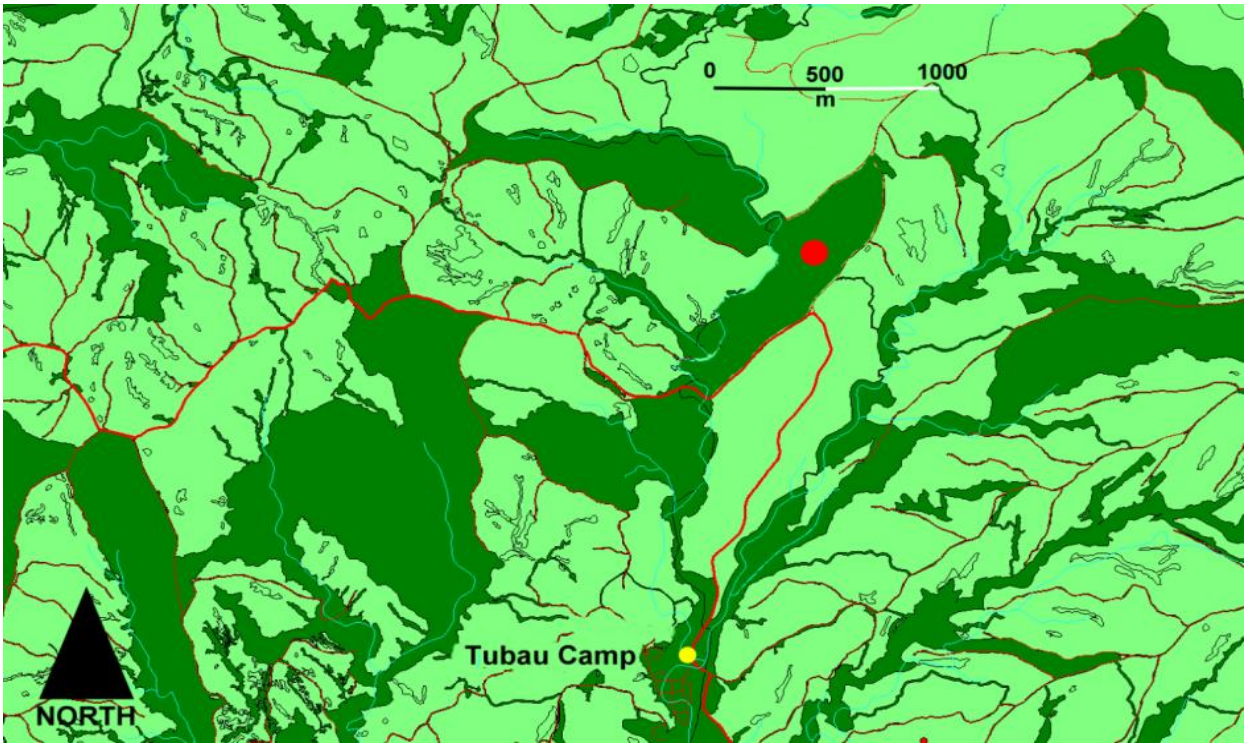

Figure 2.8: Map showing location of the Tubau trapping transect (red dot), Planted Forest Zone, Sarawak, East Malaysia. (dark green = secondary forest; light green = plantation compartments; red lines = forest road networks; blue lines = waterways).

Pilot Study: The live trapping and spool and line tracking fieldwork carried out in 2006 at the Samarakan Conservation Forest and Sungai Mina Wildlife Corridor was conducted as a pilot study aimed at identifying species present, and also for testing a range of field techniques including 1) type of bait, 2) placement of traps, and 3) the practicality of applying the spool and line method in the forest type. Given the low trap catch indices derived from these two sampling sessions, it became clear that in order to sample elusive and rare species of small terrestrial mammals in the forest fragments, a specialised sampling design would be required that did not necessarily conform with standardised small mammal inventory protocols as set out in the plantations Conservation Management Plan. Thus it was decided that instead, sampling efforts would be directed at harvesting as many suitable individuals as possible for the radio telemetry and spool-and-line studies at the expense of more robust and consistent sampling protocols that

could have yielded more meaningful diversity indices. This was achieved by the fine scale placement and orientation of traps in locations assumed to be frequented by the target species; non-arboreal treeshrews, squirrels and rats, and as advised by staff with prior small mammal trapping and research experience in local conditions. Also, the decision on whether to use transects or gird trapping designs was dictated largely by the shape and area of the forest patch in which sampling was being conducted. Accordingly both line-transect (Kalabat, Kelawit, Lana Road, Samarakan, Sungia Mina and Tubau) and grid trapping layouts (Kakus East & West, and Kapur Patches One & Two) were used.

Trapping: As the study aimed to capture animals occupying a very specific niche (the forest floor), a sampling bias in favour of non-arboreal small mammals was created as a result of locating all traps at ground level and/or in association with downed woody debris. Capture-mark-recapture data were not collected due to a subset of animals being harvested for release in other forest patches as part of spool-and-line (Chapter 3) and radio telemetry (Chapter 4) studies, while individuals in the remaining subset were released again at their respective points of capture, thus creating a second sampling bias. However measurement bias was overcome by careful training and supervision of field assistants to ensure that trap set-up was consistent, and regular checking/auditing of trap lines and grids was performed by either myself or other experienced field staff. Excluding the 2006 trapping session in Samarakan Conservation Forest, ripe aromatic banana was used as bait in all traps, thereby effectively controlling for this aspect of measurement bias.

For line transects, 100 Sherman 160 x 160 x 450 mm wire sprung cage traps were located in pairs at 20 m intervals either side of a 1000 m transect at each of the line transect trapping sites with the exception of Samarakan (2006), Sungai Mina (2006) and Lana Road (2010) where 50,

45 and 50 traps were deployed respectively. For grid layouts, 49 Sherman traps were set at 15 m intervals along seven 90m transects spaced 15m apart to sample an area of approximately one-hectare. Although some trapping sessions were extended beyond seven nights to ensure sufficient numbers of individuals were procured for the tracking exercises, this paper reports on and discusses trap captures for the first seven trapping nights only, in order that trapping effort is standardised between sites and years.

No arboreal traps were deployed during any of the trapping sessions with the exception of the 2006 Samarakan Conservation Forest session where 25 of the 50 traps were set at heights of one-to-two metres above ground level. Instead all other traps were set at ground level, and where present in association with large diameter coarse woody debris (fallen tree trunks, upturned root plates and/or branches lying at or near the forest floor) in order to target terrestrial small mammal species and avoid those with a more arboreal habit. Traps were baited with ripe aromatic banana and checked at least once daily for the duration of the trapping session. Traps were not pre-baited, and baits were changed at least every two days dependent on weather conditions and/or consumption by invertebrates.

Animal Handling: Animals and their gender were identified in the field using the Payne and Francis (2005) Field Guide to the Mammals of Borneo. Those not required for tracking were marked and released immediately at the point of capture. Animals collected for the tracking studies were transferred to cloth bags by gently tapping the end of the cage and allowing the animal to drop into the opened bag. All research on live animals followed American Society of Mammalogists (ASM) guidelines (Gannon *et al.* 2007) and was approved by the University of Canterbury Animal Ethics Committee.

Analysis: Statistical analysis was performed using the statistical software package MiniTab 15™. Linear regression was performed to detect any trend between forest patch size and 1) species richness, and 2) trap catch index of small non-volant mammals. Statistical significance was determined to be $P = < 0.050$. Due to the use of non-standardised trapping protocols employed in this phase of the study, species diversity indices were not able to be calculated.

2.3 Results

From 7287 trap nights a total of 196 individuals were recorded from the trapping sessions representing 14 species from the families Tupaiidae (five species), Sciuridae (three species) and Muridae (six species) (Table 2.2). Trapping success from forest patches ranged from a single animal *(Maxomys rajah)* at Kapur Patch One (0.29% trap catch index), to 34 individuals at the SCF patch in 2010 (4.86% trap catch index) (Table 2.3). Trap by-catches included turtles, a range of large invertebrates, a common palm civet *(Paradoxurus hermaphrodites)* and a catfish; the latter trapped at the Samarakan Conservation Forest as a result of localised flooding after a heavy rainfall event. These individuals were excluded from any further analysis and discussion.

The mean number of species sampled in individual patches was seven, ranging from one species at the Kapur-1 patch to ten at the Samarakan Conservation Forest (Figure 2.2). Across all sites, trap catch index was not found to be correlated with patch size, and neither was species richness.

The most abundant species' trapped were the brown spiny rat *(Maxomys rajah)* (n = 49) and the painted treeshrew *(Tupaia picta)* (n = 35), together representing 43.58% of the total trap catch. Brown spiny rats were caught in all except the third smallest patch (Lana Road; 5.50 ha), and *T. picta* were sampled in all except the second smallest patch (Kapur 2; 1.30 ha) and the largest forest patch (Kalabat; >500 ha) and were consistently more often caught in the Samarakan

Conservation Forest (77.50 ha). A significant positive correlation was found between patch size and trap catch index for *M. rajah* (linear regression S = 0.2682, *P* = 0.019) (Figure 2.10), however no correlation was found for *T. picta*.

Table 2.2: Number of individuals caught from ten forest patches (ranked in order of patch size) in the Planted Forest Zone, Sarawak, East Malaysia. Note that the Samarakan Conservation Forest (SCF) is sampled on five occasions, and that trapping at this forest patch in 2006 included use of 50% arboreal traps.

Animal	Kapur One 2009 (1.0 ha)	Kapur Two 2009 (1.30 ha)	Lana Road 2010 (5.50 ha)	Kakus West 2009 (38.70 ha)	Samarakan 2006 (77.50 ha)	Samarakan 2007 (77.50 ha)	Samarakan 2008 (77.50 ha)	Samarakan 2010 a (77.50 ha)	Samarakan 2010b (77.50 ha)	Kakus East 2009 (135 ha)	Tubau 2007 (200 ha)	Kelawit 2007 (250 ha)	Sungai Mina 2006 (375 ha)	Kalabat 2007 (>500 ha)	TOTAL
Tupaiidae															
Tupaia gracilis				1		2		1	6	1	1				**12**
Tupaia longipes			1	2		2		3	2			3		1	**14**
Tupaia picta		1	1	1	3	6	6	5	5	2	2	2	1		**35**
Tupaia tana					1	3		5	1			1			**11**
Ptilocercus lowii					1										**1**
Sciuridae															
Calosciurus notatus					7	3						2			**12**
Lariscus insignis			1		1	1		3	1						**7**
Sundsciurus lowi						2		2	4				1		**9**
Muridae															
Leopoldamys sabanus								1			1			2	**4**
Maxomys rajah	1	2		3	3	2	2	3	9	1	7	5	3	8	**49**
Maxomys whiteheadi						1			4					1	**6**
Niviventer cremoriventer						4			2			11			**17**
Rattus tiomanica		1		2	1			1							**5**
Sundamys mulleri			1	1				3			3	6			**14**
Total Captures	**1**	**4**	**4**	**10**	**17**	**26**	**8**	**27**	**34**	**4**	**14**	**30**	**5**	**12**	**196**
Number of Species	**1**	**3**	**4**	**6**	**7**	**10**	**2**	**10**	**9**	**3**	**5**	**7**	**3**	**4**	**14**
Total Trap Nights	**343**	**343**	**350**	**343**	**350**	**700**	**700**	**700**	**700**	**343**	**700**	**700**	**315**	**700**	**7287**

Table 2.3: Trapping success in ten remnant forest patches (ranked in order of patch size) in the Planted Forest Zone, Sarawak, East Malaysia. Numbers in parentheses (*) indicate number of species caught. Note that the 2006 Samarakan Conservation Forest data is excluded from this table due to the use of arboreal traps during this session.

Trapping Site	Patch Area (ha)	Total Captures	Trap Catch Index	Total Tupaiids	Total Murids
Kapur One	1.00	1(1)	0.29%	1(1)	3(2)
Kapur Two	1.30	4(3)	1.17%	0(0)	1(1)
Lana Road	5.50	4(4)	1.14%	2(2)	1(1)
Kakus West	38.70	10(6)	2.92%	4(3)	6(3)
Samarakan 2007	77.50	26(10)	3.71%	13(4)	7(3)
Samarakan 2008	77.50	8(2)	1.14%	6(1)	2(1)
Samarakan 2010a	77.50	27(10)	3.86%	14(4)	8(4)
Samarakan 2010b	77.50	34(9)	4.86%	14(4)	15(3)
Samarakan (Mean)	77.50	24(7)	3.39%	12(3)	8(3)
Kakus East	135.00	5(3)	1.46%	4(2)	1(1)
Tubau	200.00	14(5)	2.00%	3(2)	11(3)
Kelawit	250.00	30(7)	4.29%	6(3)	24(4)
Sg MIna	375.00	5(3)	1.59%	1(1)	3(1)
Kalabat	>500.00	12(4)	1.71%	1(1)	11(3)

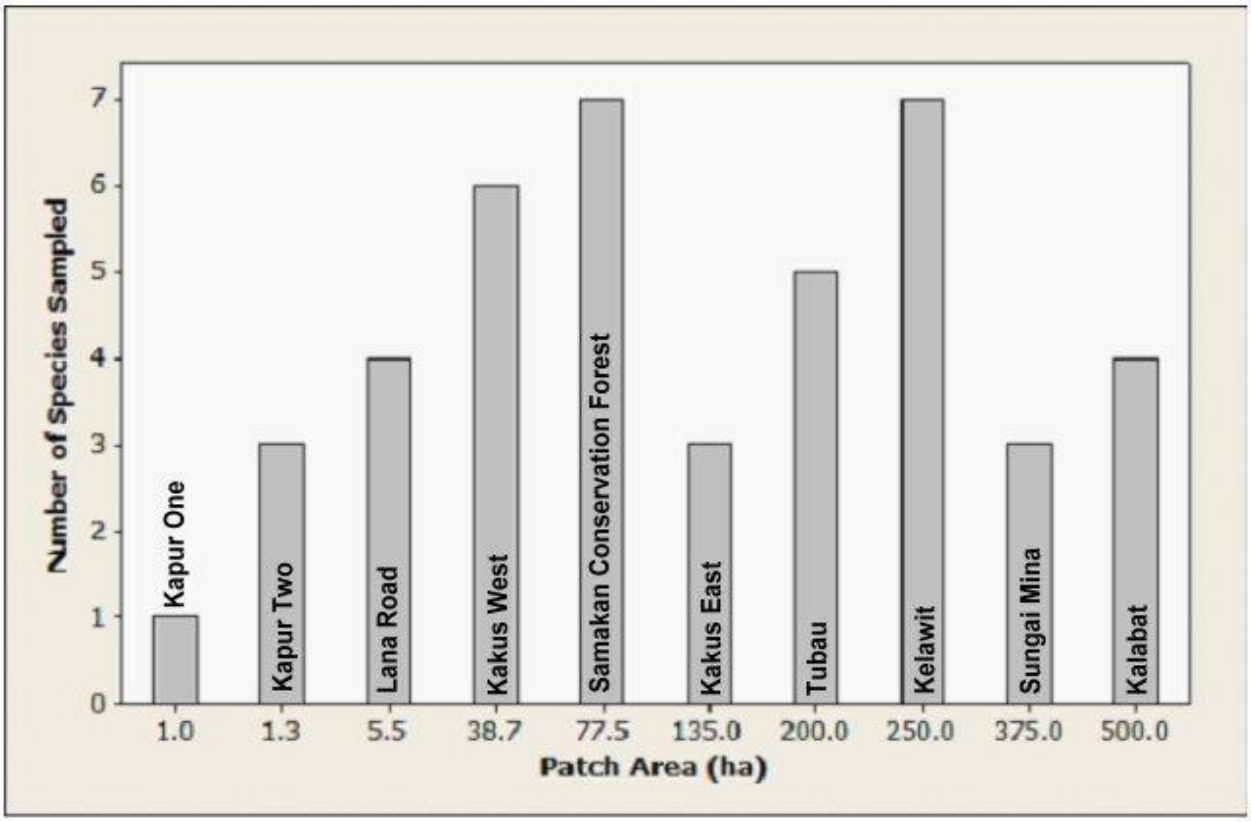

Figure 2.9: Bar chart showing number of species trapped compared with patch area.

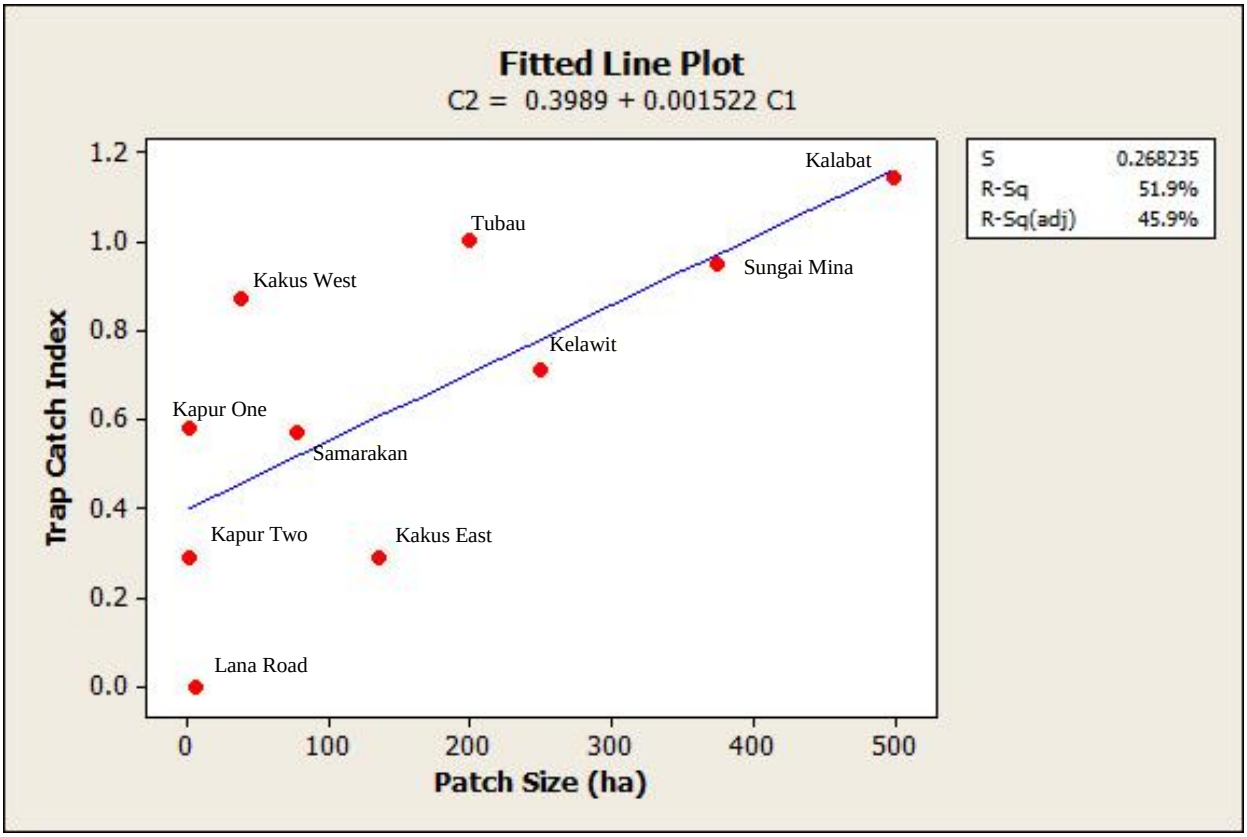

Figure 2.10: Regression between patch size and trap catch index for brown spiny rat *(Maxomys rajah)* in secondary forest fragments in the Planted Forest Zone, Sarawak, East Malaysia.

2.4 Discussion

Animal populations tend to fluctuate over both time (Rico *et al.* 2007) and space (Barnett and Dutton 1995; World Conservation Monitoring Centre 1992) which can make conclusions from population sampling difficult to draw, especially when few trapping inventories are carried out across an area. In addition to this current study, GPCon have carried out regular sampling of small mammals at a range of sites across the PFZ including in both acacia and secondary forest. However while such inventories should be of fundamental importance in assessing the state of biodiversity across the PFZ landscape, incomplete data sets in terms of trapping locations, patch sizes, trapping protocols and issues of data ownership meant that this data was mostly not able to be incorporated into this current study.

Trapping success of rainforest rodents is described by Voss and Emmons (1996) as being typically low even in the best of circumstances, and particularly low in the lowland tropics (Stone *et al.* 2008; Gotelli and Colwell 2010). Furthermore where other authors (Hin *et al.* 2007) have experienced relatively high species diversity from forest remnants throughout the PFZ, they have also identified a low relative abundance. In terms of trapping success, the placement of traps either on the ground or associated with downed woody debris proved successful in targeting the terrestrial and scansorial species required for spool-and-line and radio tracking studies, and thus avoiding those with more arboreal habits. Had this study been designed specifically to inventory non-volant small mammals rather than collect individuals for the tracking tracking studies, the use of arboreal traps and adherence to the same strict and standardised trapping protocols is likely to have provided more useful and robust data, and would have made comparisons with past species inventories more accurate. Nevertheless the data obtained from the trapping sessions reported here have provided useful findings that add to the ever coalescing database of small mammals inhabiting the PFZ.

The theory of island biogeography holds that larger patches should contain both larger populations of a species, and more species than smaller patches (Ewers and Didham 2006; Forman 1995; Hunter 2002; Lindenmayer and Pope 2000; Spellerberg and Sawyer 1999). This study did not find such a correlation, however this finding may be more to do with the low number of samples for the various sized patches, than it is to do with patch size itself given that populations tend to fluctuate over time (Barnett and Dutton 1995; Hall *et al.* 2007; World Conservation Monitoring Centre 1992). This also tends to lend evidence to nature being in constant flux rather than being in some kind of balance (Wu 2007).

Had repeated sampling of the range of patches been conducted over time, as had been done at the Samarakan Conservation Forest, it is possible that such correlations would have been revealed. Therefore more, and more consistent monitoring and research of this nature is needed in the PFZ in order to provide evidence on the likely value of the range of forest patch sizes for small mammal conservation. Furthermore such monitoring is an important requirement of both the PFZ's Conservation Management Plan (Hall *et al.* 2007) and Malaysia's Sustainable Forest Management (SFM) certification scheme; the Malaysian Criteria and Indicators (MC&I) for Forest Management Certification (Forest Plantations) (MTCC 2008). Therefore if such monitoring is a requirement of both the Conservation Management Plan and certification scheme, it should be a relatively easy task to ensure that this type of data is collected and managed in such a manner that it can be accessed and used for subsequent studies of this type.

As discussed above it is generally understood that species diversity and abundance will fluctuate over both space and time, making faunal inventories difficult to rely on with any degree of confidence where the sampling efforts represent a single point in time only. To illustrate this point, the Samarakan Conservation Forest has been the focus of six small mammal inventories and other trapping sessions between 2005 (See Wilson and Helgen 2007) and 2010 that have returned variable catches despite the use of similar, although not standardised trapping techniques and protocols.

Small forest patches less than 100 hectares in area are capable of supporting a surprising representation of their original flora and fauna and are therefore well worth protection (Corlett 2009; Lindenmayer and Pope 2000; Shafer 1995). Although relatively small and linear in nature, the Samarakan Conservation Forest is illustrative of the value of such small natural forest remnants embedded within a highly modified landscape matrix. With the exception of the 2008

trapping session, this < 100 ha forest remnant has exhibited a high species richness and abundance of small mammals even compared with much larger forest patches.

For the Samarakan Conservation Forest, the cumulative species richness of non-volant small mammals increased from seven species during a rapid assessment trapping inventory carried out in 2005 (See Wilson and Helgen 2007) to 19 species by the end of this current study (2010) if Wilson and Helgen's data are included. Regarding the changes in species richness and abundance in this forest patch, it would be easy to arrive at an alarmist conclusion to the trapping inventories had sampling ceased after the 2008 session, with an 84.62% decline in species richness from 13 species to just two species, and a 75.76% drop in total captures from 33 to eight. However the 2010 trapping sessions revealed rise in both species richness and abundance to pre 2008 levels; possibly the result of no removal-trapping (for the purposes of spool and line tracking and radio telemetry studies in novel patches) being carried out in the forest patch for a period of approximately 24 months.

Whether the observed rise in species richness and abundance occurred through breeding and reproduction within the forest patch, or whether it was through re-colonisation from nearby forest patches or matrix was not determined in this study. It is also possible that the low richness and abundance in 2008 may have been a seasonal affect related to trapping not being carried out during the south-western monsoon, as was the case for all other trapping sessions reported here. In reality though, a combination of a range of phenomena may have been responsible for this observation, although for species poorly able to disperse through acacia the ability to re-colonise an isolated patch following a local extinction is likely to be fraught with difficulty. The ability of small mammal species to disperse through acacia forest is discussed in detail in the following chapters.

Brown spiny rats were collected in nine of the ten forest patches, including the two smallest patches; Kapur One and Kapur Two which were 1.00 and 1.30 ha in area respectively. Despite thorough coverage of both patches by the trapping grid layout, only a single male *M. rajah* was trapped in Kapur One, and in Kapur Two, one adult female and one juvenile male (Figure 2.11) were captured.

Figure 2.11: Juvenile brown spiny rat *(Maxomys rajah)* trapped at the Kakus Two patch, 19th August 2009 (Photograph A. Shadbolt 2009).

Populations of *M. rajah* are reported to have declined by more than 30% in the last decade as a result of commercial logging and conversion of forest habitat (Alpin 2008). Furthermore the species is not reported to be found outside of tall and secondary forest (Payne and Francis 2005), and its IUCN status has changed from 'least concern' in 1996, to 'vulnerable' (Aplin 2008). It was therefore surprising but reassuring to find this species reproducing in the small 1.30 ha Kapur Two forest remnant, completely embedded within the acacia matrix.

However regression analysis showed a positive correlation between patch area and trap catch index for *M. rajah*, with the smallest patches hosting the least number of captures (Figure 2.10). While the species was still in low abundance in the smaller patches, small patches are more vulnerable to species extinctions than larger patches that are capable of supporting larger population sizes (Forman 1995; Spellerberg and Sawyer 1999).

Both the Kalabat and Sungai Mina sites are located within the Bukit Mina Wildlife Corridor; an area of linear forest accounting for approximately 20,000 ha of forest in total (Figures 2.3 and 2.7). The Bukit Mina Wildlife Corridor links the northern boundary of the PFZ with a 15,000 ha swamp forest/limestone outcrop complex to the south at Bukit Sarang, and also to the Binyo-Penyilam conservation area in the northeast which includes approximately 25,000 ha of swamp forest and low lying kerangas (heath forest) (Piper and Cranbrook 2007). Therefore given both its large size and relationship with the Bukit Mina Wildlife Corridor, it is not surprising that the Kalabat site should host the largest population of *M. rajah*; eight captures representing 66.67% of the trap catch.

The incidence of a blind, albino *M. rajah* captured in the larger Kakus East forest patch (c. 135 ha) was an interesting finding. It is not asserted that the albinism seen in the animal was a symptom of inbreeding that could have stemmed from habitat fragmentation, as such a conclusion cannot be drawn from a single observation. However should an increased incidence of albinism or other genetic abnormalities occur in populations within the PFZ, this would lend more weight to such a hypothesis and also lends weight to the need for regular and ongoing biodiversity monitoring across the PFZ.

A small mammal trapping inventory in the Ayer Hitam Forest Reserve, Selangor, Peninsula Malaysia demonstrated that no species was found to be dominant (Zakara *et al.* 2001). However Laurance *et al.* (2001) predict that over time fragmented communities will trend towards being dominated by 1) matrix tolerant generalists, 2) disturbance-adapted opportunists, and 3) species exhibiting small area requirements. Here *M. rajah* was found to compose 25.70% of the total trap catch across the 13 trapping sessions. Excluding the Kapur Two patch where only a single *M. rajah* was captured, trap catch for this species ranged in abundance from 12.50% of the trap catch (Samarakan 2007) to 66.67% (Kalabat). Brown spiny rats have been used as an indicator species for forest quality on account of their intolerance for modified habitats, so it is therefore reassuring that the species was found to be relatively abundant in many of the sampled forest patches throughout the fragmented PFZ.

However using similar trapping protocols, other authors (Hin *et al.* 2007) report high sample sizes for *S. mulleri*, which represented 27.00% of their total trap catch across five sites in the PFZ. Over the course of the study reported here however, *S. mulleri* were found to represent just 7.82% of the total trap catch and were collected in just five of the 13 trapping sessions (Table 2.2) where they ranged in abundance from 10.00% of trap catch (Kakus West) to 25.00% (Lana Road). Hin *et al.* (2007) carried out their trapping inventories in secondary forest, swamp forest and acacia plantation compartments, and this is likely to have influenced their abundance indices for *S. mulleri.* It nevertheless demonstrates the fluctuating nature of small mammal populations through both location and time across the landscape mosaic.

This study has shown that even the smallest of forest patches are likely to have some at least temporary value to some species, whether they are providing core habitat for forest dependant species like *M. rajah*, or a resource patch as part of a more extensive home range for wider

ranging species like *T. picta* (Refer Chapter 4) that may exploit several such patches within their range (e.g. Sitompul 2004). However species richness is often correlated with fragment size (Charles and Ang 2010; Laurance *et al.* 2001), and small patches are likely to 1) remain species-poor and 2) their vulnerability to catastrophe and extinction as a result of demographic events will be heightened compared with larger reserve areas (Shafer 1995). Furthermore, colonisation rates are thought to be higher for larger patches due to their geometric shape providing a larger target for dispersers from neighbouring habitat (MacArthur and Wilson 1967; Forman 1995). However small patches may provide different benefits than large patches (Forman 1995) including plant species conservation (Arroyo-Rodriguez *et al.* 2008; Pither and Kellman 2011) provision of ecosystem services such as crop pollination (Bodin *et al.* 2006), and as shown here, potential lifeboats for small mammals following patch isolation (e.g. following forest clearance for plantation establishment, and also future harvesting of acacia trees surrounding a natural forest remnant).

Based on the findings of this study, small forest patches of c.1.00 ha that have been exempt from clearing during plantation establishment may remain species poor and host small populations of extant species only throughout much of their existence. However it must be noted that all trapping sessions reported in this paper took place in forest patches embedded within >3 year old acacia compartments. The real value of these small forest patches as lifeboats for biodiversity may therefore only be fully realised in the immediate months following the clearance of surrounding forest and/or the harvest of adjacent plantation compartments. During these phases of rapid landscape transformation, remnant forest patches (and corridors) may receive influxes of displaced refugees from the matrix, whose populations would over-time relax as patch resources were exhausted, or as they moved back out into the early rotational stages of the next plantation

crop. Such hypotheses could be supported through replicated large-scale, long-term trapping inventories in small patches across the PFZ. This would necessitate repeated sampling of these patches that would span beyond the seven year rotation length in order to record critical patch occupancy and population responses to landscape change in the matrix.

Medium sized patches exhibited the greatest species diversity and abundance, whereas the largest forest areas hosted the largest population of *M. rajah;* a species that is identified as vulnerable by the IUCN across its natural range (Alpin *et al.* 2008). If these trends were shown to continue across larger, repeated samples of forest patches, the protection and maintenance of forest patches larger than c.5.00 ha could be shown to be important for the persistence of non-volant small mammals across the PFZ landscape. This would particularly be the case if these relatively small sized forest patches continued to host as many species as did the largest forest patch (<500 ha), albeit at much lesser abundance and for unknown lengths of time.

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CHAPTER 3

Small Mammal Movement and Response to Habitat Edges in a Fragmented Plantation Landscape in Sarawak, East Malaysia

Abstract

Individuals of seven species of non-volant small mammal were trapped in areas of logged natural forest of the Planted Forest Zone (PFZ), Sarawak, East Malaysia, and translocated to small remnant patches outside of their home ranges where they were fitted with tracking spools and released to assess response to habitat edges during simulated dispersal events. All species were found to make extensive use of downed woody debris for movement, and showed varied responses to a range of habitat edges including forest roads, acacia plantation compartments, old haul trails, clearings and riparian areas. Two species of treeshrew; long-footed treeshrew (Tupaia longipes) *and painted treeshrew* (T. picta) *were shown to be able to move between the forest patch and the acacia forest while the same edges were shown to pose potential barriers to the brown spiny rat* (Maxomys rajah) *and large treeshew* (T. tana) *illustrating the different ways that species may perceive and use habitat features such as corridors. Forest roads were also found to pose potential barriers to movement and dispersal for all species, highlighting the need for collaboration and close working partnerships between forest engineers and wildlife biologists in order to ensure the preservation of robust and resilient populations of small mammals across the heavily managed landscape of the PFZ.*

Key Words: *Tupaia longipes, Tupaia picta, Tupaia tana, Maxomys rajah, Sundamys mulleri, Leopoldamys sabanus, Lariscus insignis, Acacia mangium*, fragmentation, Planted Forest Zone, translocation, dispersal.

Title Page Image: Long-footed treeshrew *(Tupaia longipes)* released in the Kakus Nursery Forest, Planted Forest Zone, Bintulu Division, Sarawak, East Malaysia (Photograph A. Shadbolt 2009).

3.1 Introduction

The effects of forest fragmentation have been widely reported in the literature for mammals (Verboom and Apeldoorn 1990; Gaines *et al.* 1997; Zollner 2000; Bakker and van Vuren 2004; Strevens 2007; Lees and Peres 2008; Mortelliti et al. 2008; Mortelliti and Boitani 2008; Holland and Bennett 2009; Shadbolt and Ragai 2010; Charles and Ang 2010). The processes of habitat loss and fragmentation are thought to be the primary causes of the extinction of populations, metapopulations and species worldwide (Gu *et al.* 2002). However in a fragmented landscape a metapopulation structure may be the only mechanism that can maintain a species' persistence for a defined period of time (Shaffer 1987), because small forest patches at increased risk of localised faunal extinctions will rely on dispersers from adjacent forest patches to re-colonise them. Therefore the ability for individuals to disperse amongst patches in a metapopulation structure will be of central significance, and is likely to be critical to long term persistence of a species in the wider landscape (Hilty *et al.* 2006).

While mammals have been shown to be vulnerable to habitat fragmentation, each species is likely to be differentially affected in terms of their responses to habitat edges. Patch configuration and corridor requirements of different species are also likely to differ from one-another, as will be each species' perception and responses to the matrix (Hilty *et al.* 2006). Therefore it is important to understand the behaviour of the species that a particular habitat is being managed for (Loney and Hobbs 1991; Soule and Gilpin 1991). While small mammal research was reported as being among the least favoured subject of zoologists and wildlife ecologists (Louis *et al.* 1988), investigations into the responses of small mammals to the effects of habitat fragmentation have increased in recent years (Wells 2005).

Lidicker and Koenig (1996) identify seven ways in which mammals may respond to habitat patch boundaries. These range from a total avoidance of edge features, to an ability to move freely across them. The five intermediate responses include 1) an immediate retreat from the patch edge once encountered, 2) following the edge for a distance before returning to the interior, 3) an initial retreat from the edge before a second cautious approach and subsequent movement across the patch edge, 4) following the edge for a distance before crossing, and 5) cautiously approaching the edge before moving directly across. This study investigates the pertinent question of how might individuals of different non-volant small mammal species, traversing unfamiliar territory, respond when confronted with habitat edge features, and might these features act as barriers to dispersal.

The study uses spool-and-line tracking of small mammals that are translocated to and released in novel habitats to explore the behavior of individuals during simulated dispersal or exploratory excursions through unfamiliar environments outside of their home ranges. It seeks to understand how different species may differentially perceive and react to habitat edges and the matrix beyond, with the null hypothesis that individuals will cross edge features at random. The results enable a prediction as to which species are able to tolerate different scales of habitat fragmentation, and conversely which species are likely to be more at risk from the effects of fragmentation.

Where a species is shown to be intolerant of habitat edges, this may have wider affects on population and community ecology where the group of sub-populations distributed across a fragmented landscape are unable to function as a metapopulation. Sub-populations isolated in

this manner are therefore likely to be more vulnerable to local extinctions in the absence of re-colonisation events from adjacent habitats. Consequently, as more and more isolated patches experience local extinctions, area-wide extinctions of fragmentation-intolerant species could occur.

Many studies have used radio telemetry or trapping to infer response to habitat edges, however few have used direct observation (Lidicker and Koenig 1996). Furthermore, McCullough (1996) identifies that many studies that have began with good sample sizes have failed as a result of too few animals reaching dispersal age, and accordingly conclusions are based on a small set of observations.

Direct observations of animals in their natural environment are often impractical due to the considerable distances that some species are able to move in relatively short timeframes, and may also be impractical for more secretive species such as small mammals (McCullough 1996). Direct observation of wildlife also suffers from the paradox of observer effect; the influence on the behavior of the subject imposed by the very presence of the observer. This problem is likely to be compounded in shy and secretive species like non-volant small mammals; particularly treeshrews (E.g. Emmons 2000).

While radio telemetry remains a dominant and essential tool in wildlife research (Millspaugh and Marzluff 2001), including the study of dispersal behavior, its practicality in identifying animal pathways, stopovers and avoidances is limited by the frequency of fixes and the ability of the fieldworker to keep up with its continuing movement (McCullough1996, Emmons 2000). Furthermore, the collection of location point-data derived from radio telemetry reveals to us the location of the subject animal at a series of single points in time, but is likely to tell us very little

of the route the animal took between these points unless backed up by frequent fixes or direct observation. Thus there may be a good chance that we inadvertently miss the very behavioral event we sought to investigate in the first instance; in this case response to habitat edge and use of movement substrate.

While not technically direct observation, spool-and-line tracking may be the nearest we can come to directly observing edge behavior of often secretive species like small mammals without unduly influencing or biasing their behavior. Spool-and-line tracking involves the attachment of a small spool of thread to an animal to record its fine scale movement patterns and habitat use. As the animal moves off through the forest, the fine nylon thread plays out from the spool casing and snags on leaf litter, fern and coarse woody debris etc to reveal the shape of its movement path in fine detail which can be recorded accurately to the nearest 100mm. The method has been described as comical and generally more amusing than practical (Russell 2003), however as there are no other modern tracking techniques that provide the level of fine scale detail that the spool-and-line method provides (Shanahan 2007), the method is indeed invaluable, and perhaps the best method for recording fine scale habitat use and other life history characteristics in many situations.

Spool and line tracking has been used globally in many habitat types ranging from primary tropical rainforest in Borneo (Wells *et al.* 2004), to braided river systems in the South Island of New Zealand (Shanahan *et al.* 2007). The method was first applied in the 1920's in the USA by Breder (1927), for studying populations and home range of the box turtle *Terepene c. carolina* and has subsequently been used for investigating a range of biological issues including nest location of meadow voles (Boonstra and Craine 1985), perception of scale by red-backed voles *(Clethrionomys gapperi)* (Nams 1996), use of downed woody debris by chipmunks (Zollner and

Crane 2003), movement trajectories and habitat partitioning of small mammals *(*Wells *et al.* 2006b), impacts and effects of power line easements on small mammals, (Strevens 2007) and the effects of habitat fragmentation on the brown spiny rat *(Maxomys rajah)* (Shadbolt and Ragai 2010) to name but a few.

This study therefore uses the spool-and-line method to record and compare the responses of seven species of non-volant, terrestrial small mammals: long footed treeshrew *(Tupaia longipes)* painted treeshrew *(T. picta)*, large treeshrew *(T. tana)* , brown spiny rat *(Maxomys rajah)*, Mullers rat *(Sundamys mulleri)*, long tailed giant rat *(Leopoldamys sabanus)* and the three striped ground squirrel *(Lariscus insignis)* to a range of forest edges of both natural and anthropogenic origin in the fragmented landscape of a large scale industrial *Acacia mangium* timber plantation in Sarawak, East Malaysia. The study aims to record fine-scale behavior during a simulated dispersal event by trans-locating the small mammals fitted with spool-and-line devices from large forest tracts to small (approx 1 ha) unfamiliar forest patches outside of their assumed home ranges, and embedded within a matrix of acacia plantation, forest roads, wetlands, large clearings and bisected by abandoned logging haul trails. Information gleaned from this study goes toward filling the current gaps in knowledge on how species perceive and react to habitat edges in tropical forest ecosystems, and may also be of special interest to species reintroduction/translocation practitioners in terms of animal behavior immediately post-release.

The hypotheses of this study are that these small non-volant mammals will 1) have varying responses to habitat edge features, ranging from moving freely across edges when encountered to immediately retreating from them as described by Lidicker and Koenig (1996), and 2) that the cumulative result of these individual responses will reveal some species to be more sensitive to habitat fragmentation and population isolation than others. I also predict that movement patterns

(use of substrate, path tortuosity, directionality and flight response) of individuals translocated to the novel patches will differ to those of a control group of individuals released at their respective points of capture.

3.2 Methods

3.2.1 Study Sites

The study was conducted in the Planted Forest Zone (PFZ) situated between longitude 113^{o}00' and 113^{o}15' East and latitude 3^{o}15' and 3^{o}00' North in the Bintulu Division, Sarawak, East Malaysia (Figure 2.1, Chapter 2). The study area ranged in elevation from 30 to 80m above sea level and consisted of a cut-over mixed dipterocarp and kerangas forest mosaic in the process of being converted to a fast growing *A. mangium* plantation. The climate of Sarawak is described in Chapter 2.

Fieldwork for spool and line tracking was carried out during the 2006, 2007, 2009 and 2010 field sessions listed in Table 2.1, Chapter 2. Within these sessions, trapping was carried out at eight sites within the PFZ: Kalabat, Kapur-1, Kapur-2, Kelawit, Lana Road, Samarakan Conservation Forest (SCF), Sungai Mina Conservation Corridor and Tubau. One trapping session was conducted at each site with the exception of SCF were five trapping sessions were conducted.

Potentially suitable release patches for the translocation experiment were identified from plantation stock maps prior to visiting the areas, and were later assessed in the field in terms of their ability to be accessed, forest condition, and suitability of forest edges. Release patches were selected only if they were characterised by defined edges with acacia compartments, forest roads, old haul-trails and riparian areas, and that were considered small enough that released animals

would have a good probability of encountering such edges within the range of the spool device (240 m). Release patches ranged in distance from the respective trapping sites from 500m (Kalabat) to >3km (Kelawit). Furthermore, all experimental release patches were separated from the sites of capture by areas of acacia plantation, secondary forest and forest road networks, and were thus considered to be unfamiliar to the subject animals.

One suitable patch of secondary forest was selected for animal release at each study site (Table 3.1) except for at Tubau where two separate release patches were used due to two suitable patches being available within close proximity of each other. The use of two patches here resulted in a more efficient use of time and staff resources as it allowed for animals to be released at one patch while tracking of the previous day's releases was carried out at the second patch.

Table 3.1: Dates and locations of trapping and spool-and-line tracking sessions at eight sites in the Planted Forest Zone, Sarawak, East Malaysia.

Trapping Site	Dates	Release Patch	Release Patch Coordinates	Distance
Kalabat	18th – 30th June 2007		N 02°54'50.27" E 113°13'34.48"	0.5 km
Kapur-1	07th – 16th Aug 2009		N/A	N/A
Kapur-2	11th Jul – 21st Aug 2009		N/A	N/A
Kelawit	2nd – 12th Aug 2007		N 02°51'35.25" E 112°46'30.84"	4.5 km
Lana Road	05th – 15th Jul 2010		N 02°54'56.51" E 113°06'18.10"	2.0 km
Samarakan Conservation Forest	05th – 15th Jul 2006		N/A	N/A
Samarakan Conservation Forest	04th – 14th Jul 2007		N 02°54'56.51" E 113°06'18.10"	3.5 km
Samarakan Conservation Forest	22nd Oct – 6th Nov 2008		N 02°54'56.51" E 113°06'18.10"	3.5 km
Samarakan Conservation Forest	20th– 30th Jun 2010		N 02°54'56.51" E 113°06'18.10"	3.5 km
Samarakan Conservation Forest	05th– 18th Jul 2010		N 02°54'56.51" E 113°06'18.10"	3.5 km
Sungai Mina Conservation Corridor	21st – 31st Jul 2006		N 02°47'29.47" E 113°10'52.27"	0.5 km
Tubau	18th – 28th July 2007	Tubau 1	N 03°07'51.09" E 113°38'36.29"	0.7 km
	18th – 28th July 2007	Tubau 2	N 03°08'02.03" E 113°39'03.50"	0.8 km

3.2.2 Animal Handling

Trapping: Sherman wire sprung cage traps measuring 160 x 160 x 450mm were located either in pairs along trapping transects or on trapping grids as described in Chapter 2. Traps were set at ground level on or beside large diameter coarse woody debris (fallen tree trunks, upturned root plates and/or branches lying at or near the forest floor) where present in order to target terrestrial non-volant small mammal species and avoid those with a more arboreal habit. Traps were baited with ripe aromatic banana and checked daily for a period of seven nights for each site except where trapping periods were extended in order to source additional animals. No arboreal traps were used in order to avoid capturing species with arboreal habits, and traps were not pre-baited.

Handling and Spool Attachment: Animals not required for tracking purposes were released immediately at their point of capture after first being identified to species level using Payne and Francis (2005) field guides where necessary, and gender recorded. Individuals to be used for tracking were transferred from the wire cage traps to cloth bags by gently tapping on the end of the cage and allowing them to fall into the opened end of the bag. Animals were transported by foot and vehicle back to the field base and held in the cloth bags in a cool dark area until transported to their respective release areas. All animals used for spool-and-line trapping were treated in this same manner regardless of release site in order to reduce any potential handling bias. Diurnal species (Tupaiids and Sciurid rodents) were released mid afternoon, while the nocturnal Murid rodents were released wherever possible in the late afternoon/early evening.

Two different spool casing methods were used during the course of the study. Initially Danfield™ nylon 120/2 No.10 quilting bobbins (Texspec NZ Limited, Auckland, New Zealand) containing 240 m length lightweight nylon thread (white) measuring 40 mm x 15 mm and

weighing 5 g were wrapped with plastic food wrap and then wrapped with 12.5 mm zinc oxide adhesive plaster tape (Snowflake™, Shanghai China) (weight 0.5 g). The second method involved the same Danfield™ quilting bobbins, but encased in heat-shrink plastic tubing and shrunk to size over a naked flame. Both spool devices were prepared at the field base prior to animal release.

In the field, cyanoacrylic adhesive was applied directly to the spool casing, allowed to become tacky and held firmly against the animal's fur in the centre of the upper back area near the shoulders (Figure 3.1). The spool device was manually held in place for up to 20 seconds while the adhesive dried. During the initial spool-and-line tracking attempts, the hair on the upper back of the animal was clipped short prior to attaching the spool device. However these early trials revealed that spools remained attached longer if the hair was not trimmed. Furthermore, by not trimming, the time that animals were subjected to human handling was also substantially reduced, and therefore following these first spooling attempts hair was no longer trimmed. No animals were anaesthetized during any stage of their handling.

Once spools were securely in place, animals were left in half open bags while field workers retreated from the release area. Assistance was given only if animals did not leave their bags within a few minutes to avoid animals becoming entangled in the nylon thread. Where assistance was required, this was administered by gently tipping the animal from the bag on one side of a large diameter tree trunk with the fieldworker out of immediate view on the opposite side of the trunk.

All research on live animals followed American Society of Mammalogists (ASM) guidelines (Gannon *et al.* 2007) and was approved by the University of Canterbury Animal Ethics Committee.

Figure 3.18: Spool-and-line package attached to a painted treeshrew (Tupaia picta) prior to release (Photograph A. Shadbolt 2006).

3.2.3 Animal Tracking

Step Length & Turning Angle: On the morning following release, the route of the animal as revealed by the path of the nylon thread (Figure 3.2) was recorded by measuring step-lengths (the straight-line distance travelled between distinct changes of direction) to the nearest 10 cm and nearest degree using a 100 m tape measure and a sighting compass respectively. This data was collected in order to analyse substrate use, path tortuosity, directionality and potential flight

responses. Compass bearings were not relative to any geographic feature (such as point of capture) except magnetic north, but rather were used solely to accurately calculate turning angle and produce animal movement paths for analysis.

Movement Substrate: Use of substrate was grouped under the three categories: G (ground); L (log); and B (branch), and recorded for the entire length of the tracked thread. Qualitative habitat variables that described vegetation class, edge type and various fine scale landscape elements encountered by the animal were also recorded along the route. Step lengths up to and including the first ten metres of spool were not used in analysis unless otherwise stated in order to eliminate any immediate flight response from the data.

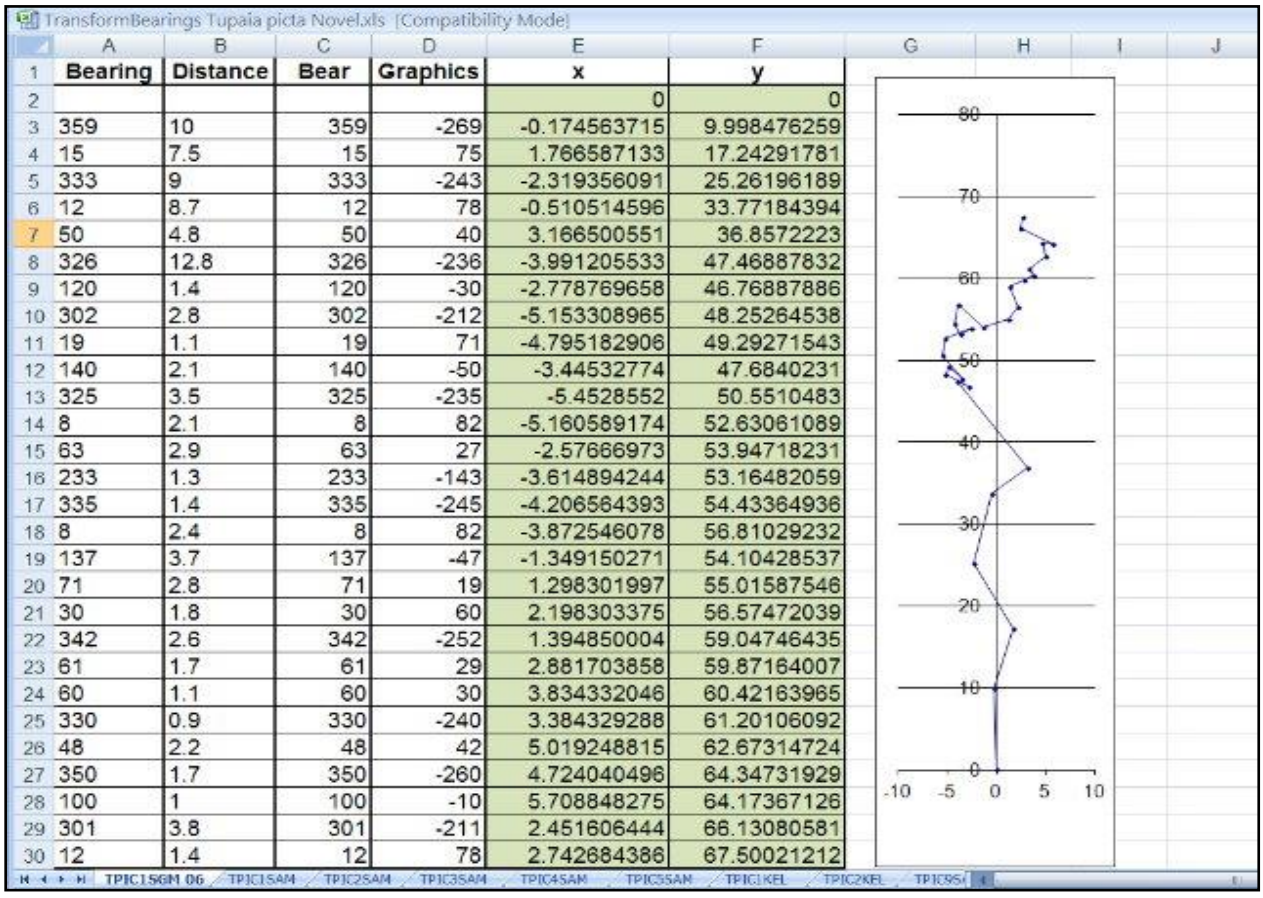
Figure 3.2: Nylon thread revealing movement path of a painted treeshrew *(Tupaia picta)* released in plantation compartment T1A, Planted Forest Zone, Sarawak, East Malaysia. (Photograph A. Shadbolt, 2007).

Edge Definition: Habitat edges and linear landscape features were grouped under five categories: roads, haul trails, acacia plantation, riparian (including wetland) areas and open clearings. Roads were deemed to differ from haul trails due to their mineral earth or loose chip surface, lack of overhead canopy, occurrence of vehicle traffic and were typically in excess of 10 m wide. Conversely, haul-trails were typically much narrower and were no longer used by vehicular traffic. They were characterised by the presence of overhead tree canopy closure, and by leaf-litter accumulation and sporadic seedling/sapling regeneration.

Where the patches adjoined acacia compartments, low contrast edges were created as a result of the comparatively low tree diversity in the acacia stand. Other factors contributing to this contrast included a lower tree and canopy height and different under-storey characteristics in the acacia consisting of sparse fern, exposed mineral soils and sparse, un-decomposed leaf-litter. Riparian areas included both wetland areas and small streams that resulted in abrupt changes in vegetation type and the presence of open/running water, whereas clearings were characterised by wide areas lacking overhead canopy cover and vegetated with pioneer species such as dense grasses and ferns.

Response to Edges: Responses to these features were recorded as binary responses where one (1) represents a movement across the edge features, and zero (0) where an animal did not cross. Where an animal did not cross the feature, the movement pattern was described as either parallel (a parallel movement along the feature then away), or away (a definite movement away from the feature). As per Prevedello and Vieira (2010), movements parallel with edges included all those movements estimated to be between 0 and 45^{o} from the azimuth of the edge feature.

Generation of Animal Movement Paths: Animal movement paths were generated by firstly converting compass bearings to graphical orientation with 0^o orientated 90^o clockwise (IE east), and then transforming the resulting bearings and distances to x and y coordinates. Coordinates were then used to produce simple x - y scatter-plots connected by straight lines and markers to create the plot of the movement path. These operations were performed using equations and graphing functions in Microsoft Excel® software as shown in Figure 3.3 and discussed below.



TransformBearings Tupaia picta Novel.xls [Compatibility Mode]

	A	B	C	D	E	F
1	Bearing	Distance	Bear	Graphics	x	y
2					0	0
3	359	10	359	-269	-0.174563715	9.998476259
4	15	7.5	15	75	1.766587133	17.24291781
5	333	9	333	-243	-2.319356091	25.26196189
6	12	8.7	12	78	-0.510514596	33.77184394
7	50	4.8	50	40	3.166500551	36.8572223
8	326	12.8	326	-236	-3.991205533	47.46887832
9	120	1.4	120	-30	-2.778769658	46.76887886
10	302	2.8	302	-212	-5.153308965	48.25264538
11	19	1.1	19	71	-4.795182906	49.29271543
12	140	2.1	140	-50	-3.44532774	47.6840231
13	325	3.5	325	-235	-5.4528552	50.5510483
14	8	2.1	8	82	-5.160589174	52.63061089
15	63	2.9	63	27	-2.57666973	53.94718231
16	233	1.3	233	-143	-3.614894244	53.16482059
17	335	1.4	335	-245	-4.206564393	54.43364936
18	8	2.4	8	82	-3.872546078	56.81029232
19	137	3.7	137	-47	-1.349150271	54.10428537
20	71	2.8	71	19	1.298301997	55.01587546
21	30	1.8	30	60	2.198303375	56.57472039
22	342	2.6	342	-252	1.394850004	59.04746435
23	61	1.7	61	29	2.881703858	59.87164007
24	60	1.1	60	30	3.834332046	60.42163965
25	330	0.9	330	-240	3.384329288	61.20106092
26	48	2.2	48	42	5.019248815	62.67314724
27	350	1.7	350	-260	4.724040496	64.34731929
28	100	1	100	-10	5.708848275	64.17367126
29	301	3.8	301	-211	2.451606444	66.13080581
30	12	1.4	12	78	2.742684386	67.50021212

Figure 3.3: Microsoft Excel® spreadsheet illustrating method of generating a simple animal movement path from field data (refer text below for full description of procedure).

In Figure 3.3 (above), columns A and B contain the movement bearings and distances (step lengths) measured in degrees and metres respectively that were recorded in the field. Column C corrects for any bearings that may have been recorded as bearings less than 0^o using the Excel®

formula: =IF(A3<0,A3+360,A3) in cell C3. In this example, no bearings were recorded as negatives. Column D converts the corrected compass bearings from Column A to graphical orientation using the Excel® formula: =-C3+90 in cell D3. Columns E and F use the Excel® formulae: =E2+COS(D3*3.14159/180)*B3 and =F2+SIN(D3*3.14159/180)*B3 respectively in cells E3 and F3 to produce the line-connected x - y scatter plots representing the animal movement path. The x – y coordinates generated in columns E and F can then be used for input into other software packages for further movement analysis as discussed below.

3.2.4 Data Analysis

Statistical analysis was performed using the statistical software packages MiniTab 15™, Biotas™ version 2.0a 3.7 (Ecological Software Solutions™), and Fractal 5.20 (Nams 2005). The lower threshold of all statistical significance was determined to be $P = < 0.050$.

Tortuosity: Path tortuosity was determined using the mean fractal dimension (D Mean) method in the software package Fractal 5.20 (Nams 2005). D Mean is calculated within the software package by walking increasingly larger and larger dividers in two directions over the path to yield a single overall estimate for D over the range of scales. This method is discussed in detail in Nams (2005). A Fractal D Mean of one (1) represents a straight line movement regardless of the scale of resolution, and a D of two (2) represents a path that is so tortuous that over time the path represents a Brownian motion that would cover an entire plane (Nams 2006, Turchin 1996).

Substrate Use: Use of substrate was analysed in MiniTab 15™ with One-way Analysis of Variance (ANOVA), pair-wise Tukey's tests and Two Sampled T-tests. Here the null hypotheses were that mean step lengths would 1) be the same length regardless of the substrate type, and 2)

be the same regardless of species. Comparisons were also made between animals released in unfamiliar forest patches and those of the same species released at their point of capture. Here the same analysis methods were used, with the null hypothesis being that both samples would exhibit the same movement behaviour.

Flight Response: Correlation coefficients (r) between 1) step length and 2) turning angle in terms of their distance from point of release were calculated using linear regression. Excluding the first ten metres of travel, the mean step lengths and turning angles on the ground for consecutive 20 m segments were calculated for each individual, and these individual means were pooled to give overall means by distance from origin.

Correlation between turning angle and distance from the point of release within the first 50 step lengths was also calculated. This test included the first ten metres of movement in order to detect any trend in path tortuosity that may indicate an immediate flight response post release. Statistical comparisons of distance travelled before first use of protective cover within the first 100 m of tracked movement path between species was performed in MiniTab 15™ using Two Sampled T-tests, and included the first ten metres of thread.

3.3 Results

During the study, 51 individuals of seven species were captured, fitted with tracking spools and released in novel patches and tracked over distances ranging from 11.50 m to 245.10 m (mean 143.69 m). These included long footed treeshrew *(Tupaia longipes)* n = 8; painted treeshrew *(T. picta)* n = 10; large treeshrew *(T. tana)* n = 9; brown spiny rat *(Maxomys rajah)* n = 15; Muller's rat (*Sundamys mulleri*) n = 6; long tailed giant rat (*Leopoldamys sabanus)* n = 2; and three striped ground squirrel (*Lariscus insignis)* n = 1.

Twenty-one animals were captured and released with tracking spools at their respective points of capture, with tracked distances ranging from 15.00 m to 244.00 m (mean163.46). These included *T. longipes* (n = 2), *T. picta* (n = 9), *T. tana* (n = 1), M. rajah (n = 12) and *L. insignis* (n = 4).

3.3.1 Long Footed Treeshrew (Tupaia longipes)

Five male and two female *T. longipes* were released into novel patches and tracked over a total distance of 1172.50 m. Data for a sixth male (TLON2/07), tracked for a distance of just 17.5m was also recorded, however data for this animal were used to supplement data for 1) use of protective cover and 2) mean step-length by distance from point of release only, but excluded from any other analysis.

Two animals were released and tracked in their home territories, both during the 2010 field session in the Samarakan Conservation Forest. TLON1/10 (male) was tracked for a distance of 189.00 m, while TLON4/10 (male) was tracked for 63.00 m. Neither animal was recorded seeking protective cover within the first 50 m of tracked movement path.

Response to Edge: Animals released in novel patches encountered habitat edges on 18 occasions (Table 3.2). Forest roads were encountered on five occasions, acacia compartments on seven occasions, riparian edges on six occasions, however no encounters with haul trails occurred.

Table 3.2: Response to edge features encountered by long footed treeshrews *(Tupaia longipes)*. CROSS = animal crossed over edge feature; NCParallel = animal moved parallel along feature without crossing; NCAway = animal moved away from edge feature without crossing; NCPooled = NCParallel + NCAway. Numbers in parenthesis ( ) indicate number of individuals contributing to responses.

Response	Road	Haul Trail	Acacia	Riparian	Total
CROSS	0	0	7(4)	0	7
NCParallel	5(4)	0	0	4(4)	9
NCAway	0	0	0	2(2)	2
NCPooled	5	0	0	6	11
Total	**5**	**0**	**7**	**6**	**18**

Substrate Use: Long footed treeshrews spent most of their time on the ground (Table 3.3). In novel patches only two animals (TLON4/07 and TLON8/10) were recorded using the low branches of trees: one climbed to 1.5 m above ground, and the other climbed vertically to a height of approximately ten metres upon encountering the edge of the forest patch adjoining an open wetland area, after which the thread trail was lost. Pooled mean step-lengths on logs were longer than pooled mean lengths recorded on the ground in novel patches. Movements on logs and on the ground were also longer than mean step lengths on branches in novel patches, whereas in home territories step lengths on the ground were longer than on both logs and branches. However, step lengths associated with logs, branches and on the ground were not found to differ significantly.

Table 3.3: Substrate use and Mean Fractal Dimension (D Mean) of long footed treeshrews *(Tupaia longipes)* released in novel patches and home territories. Distance = total tracked distance tracked; % Route (G = Ground) (L = Log) (B = Branch) = percent of total route on or associated the respective substrates; StLG = mean step-length on ground; StLg = mean step-length on or associated with logs, and StLB = mean step length on branches.

Animal	Site	Distance	% G	% L	% B	StL G	StL L	StL B	D Mean
Novel Patch									
TLON1/07 (F)	Samarakan	241.40 m	93.95%	6.05%	0.00%	2.55 m	6.95 m	NA	1.1822
TLON3/07 (M)	Kelawit	233.30 m	99.28%	0.72%	0.00%	2.16 m	1.60 m	NA	1.5933
TLON4/07 (F)	Kelawit	204.00 m	82.22%	16.75%	1.03%	1.91 m	2.94 m	1.00 m	1.4435
TLON5/07 (M)	Kelawit	195.30 m	87.97%	12.03%	0.00%	2.43 m	1.72 m	NA	1.1793
TLON6/10 (M)	Samarakan	205.50 m	93.25%	6.75%	0.00%	3.47 m	6.60 m	NA	1.3356
TLON7/10 (M)	Samarakan	63.00 m	93.64%	6.36%	0.00%	1.00 m	1.61 m	NA	1.2939
TLON8/10 (M)	Samarakan	30.00 m	89.44%	0.00%	10.56%	2.01 m	NA	0.95 m	1.0290
Mean		**167.50 m**	**91.39%**	**6.52%**	**1.66%**	**2.22 m**	**3.57 m**	**0.98 m**	**1.3230**
Median		**204.00 m**	**93.25%**	**6.36%**	**0.00%**	**2.16 m**	**2.16 m**	**0.98 m**	**1.2939**
Home Territory									
TLON1/10 (M)	Samarakan	189.00 m	73.37%	13.92%	11.55%	1.69 m	1.45 m	1.46 m	1.3791
TLON4/10 (M)	Samarakan	63.00 m	97.70%	2.30%	0.00%	1.50 m	1.20 m	NA	1.3944
Mean		**126.00 m**	**85.54%**	**8.11%**	**5.78%**	**1.60 m**	**1.33 m**	**1.46 m**	**1.3869**

Flight Response: The pooled mean of step lengths of the movement paths for the eight *T. longipes* on the ground were not correlated with distance from the point of release. For only one individual (TLON3/07), mean step lengths were negatively correlated with distance from release point (linear regression; S = 0.0521057, $P = 0.004$).

The pooled mean of turning angles for *T. longipes* was 42.71^{o}, ($30^{o} – 51^{o}$; median 32.36^{o}). The mean turning angles of the pooled sample tended to be negatively correlated with distance from the origin where changes in trajectory became slightly smaller with distance (r square = 2.1%). Turning angles within the first fifty steps were not correlated with distance from release point.

One individual (TLON02/07) disappeared under protective cover within the first 100 m of tracked movement path. Here the thread led to a confined space within aerial roots at the base of a tree where approximately ten metres of activity was recorded along with the detached spool casing.

3.3.2 Painted Treeshrew *(Tupaia picta)*

Five male and five female *T. picta* were released into novel patches and tracked over a total distance of 1584.70m. In home territories, five male and three females were trapped in the Samarakan Conservation Forest and released at their points of capture and tracked over a total distance of 1030.60 m (Refer Table 3.5). An additional female (TPIC2/06) and a male (TPIC3/10) were tracked in home territories for just 15.00 m and 29.10 m respectively. Data from these animals are used only to supplement observations on use of protective cover and not for any other analysis.

Response to Edge: Painted treeshrews encountered various forest edge features on 50 occasions. Tracked animals encountered forest roads on nine occasions, haul roads on 18, acacia on ten, and wetland/riparian areas on 13 occasions (See Table 3.4).

Table 3.4: Response to edge features encountered by painted treeshrews *(Tupaia picta)*. CROSS = animal crossed over edge feature; NCParallel = animal moved parallel along feature without crossing; NCAway = animal moved away from edge feature without crossing; NCPooled = NCParallel + NCAway. Numbers in parenthesis ( ) indicate number of individuals contributing to responses.

Response	Road	Haul Trail	Acacia	Riparian	Total
CROSS	0	10(4)	4(2)	0	14
NCParallel	4(3)	7(4)	5(2)	6(3)	22
NCAway	5(5)	1(1)	1(1)	7(5)	14
NCPooled	9	8	6	13	36
Total	**9**	**18**	**10**	**13**	**50**

Figures 3.4 – 4.8 (below) show examples of painted treeshrew movement paths plotted from bearings and measurements taken in the field for seven animals released at the T1A forest patch near the Samarakan Nursery in 2007.

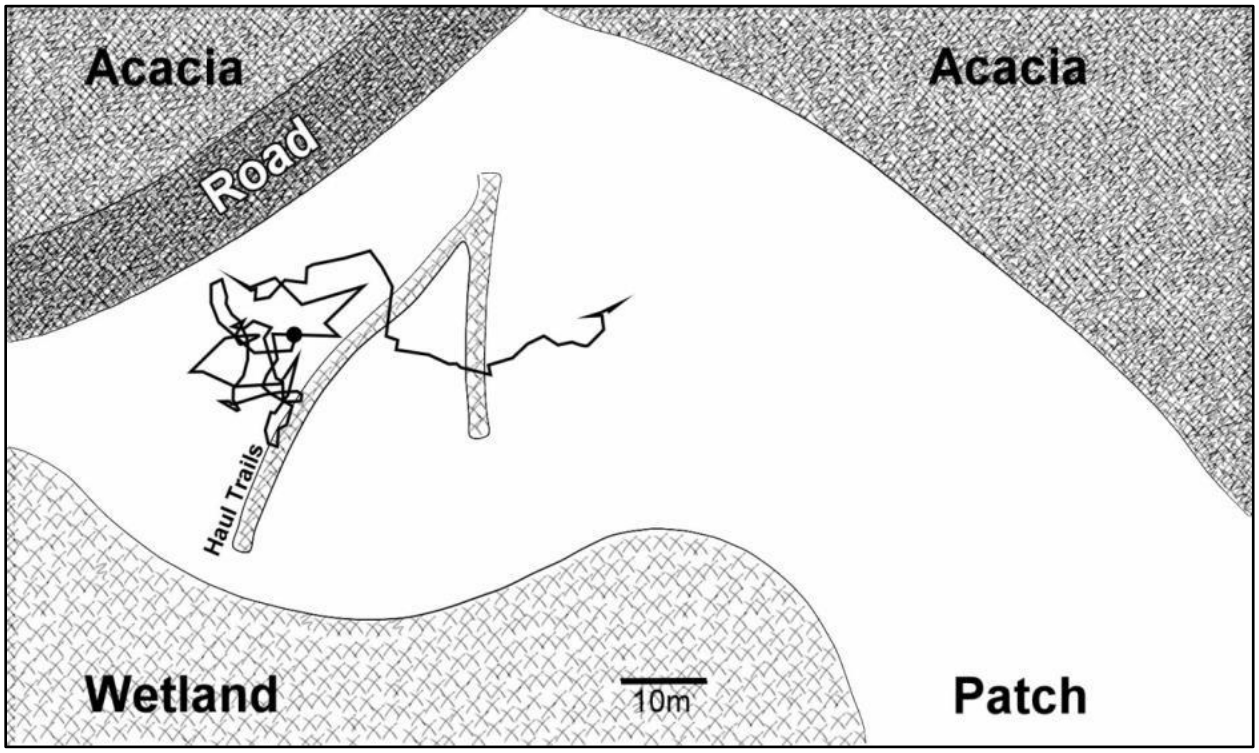


Figure 3.4: Painted treeshrew *(Tupaia picta)* (TPIC1/07) movement trajectory in T1A forest patch showing behaviour at edges (•= point of release).

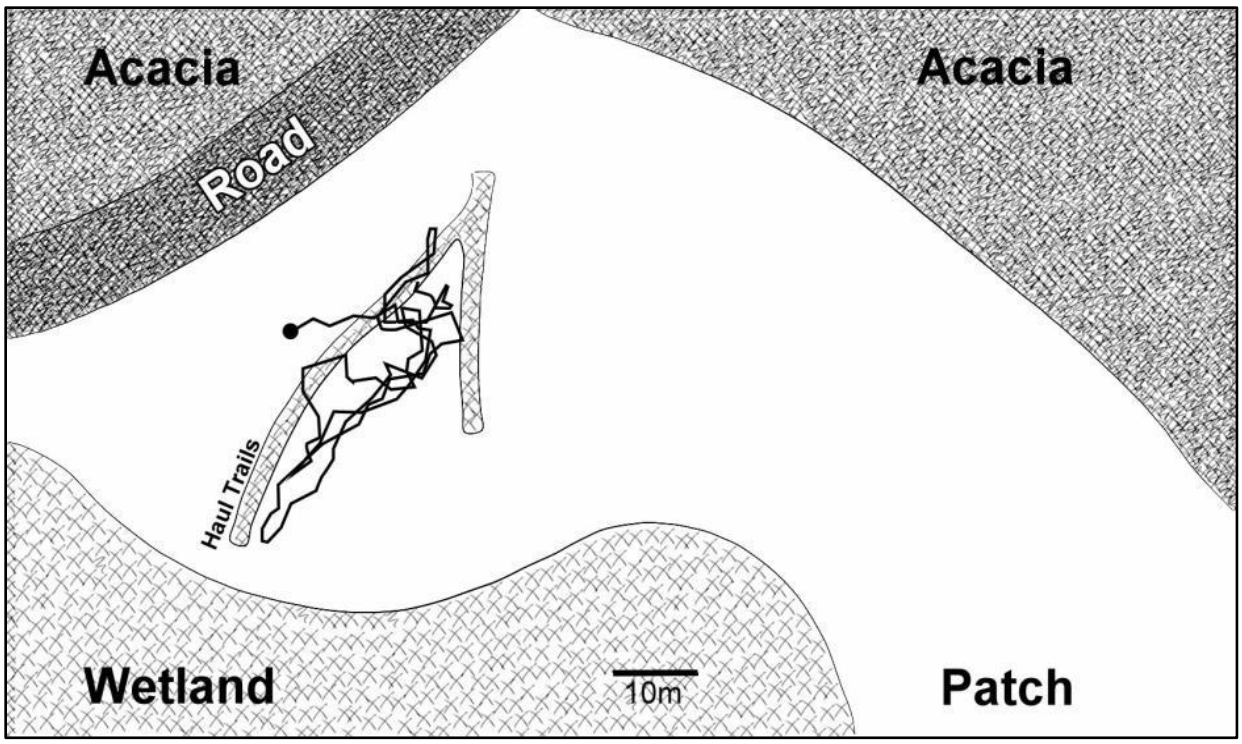


Figure 3.5: Painted treeshrew *(Tupaia picta)* (TPIC2/07) movement trajectory in T1A forest patch showing behaviour at edges (•= point of release).

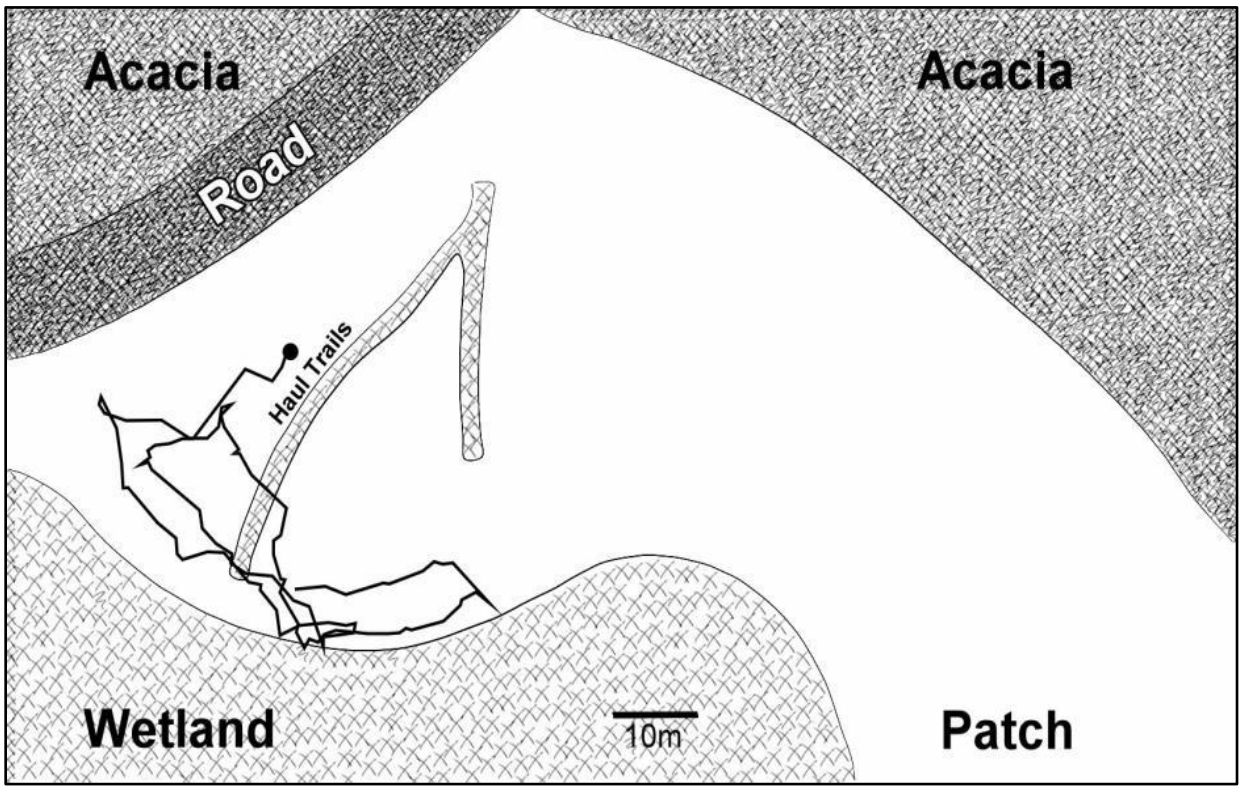


Figure 3.6: Painted treeshrew *(Tupaia picta)* (TPIC3/07) movement trajectory in T1A forest patch showing behaviour at edges (•= point of release).

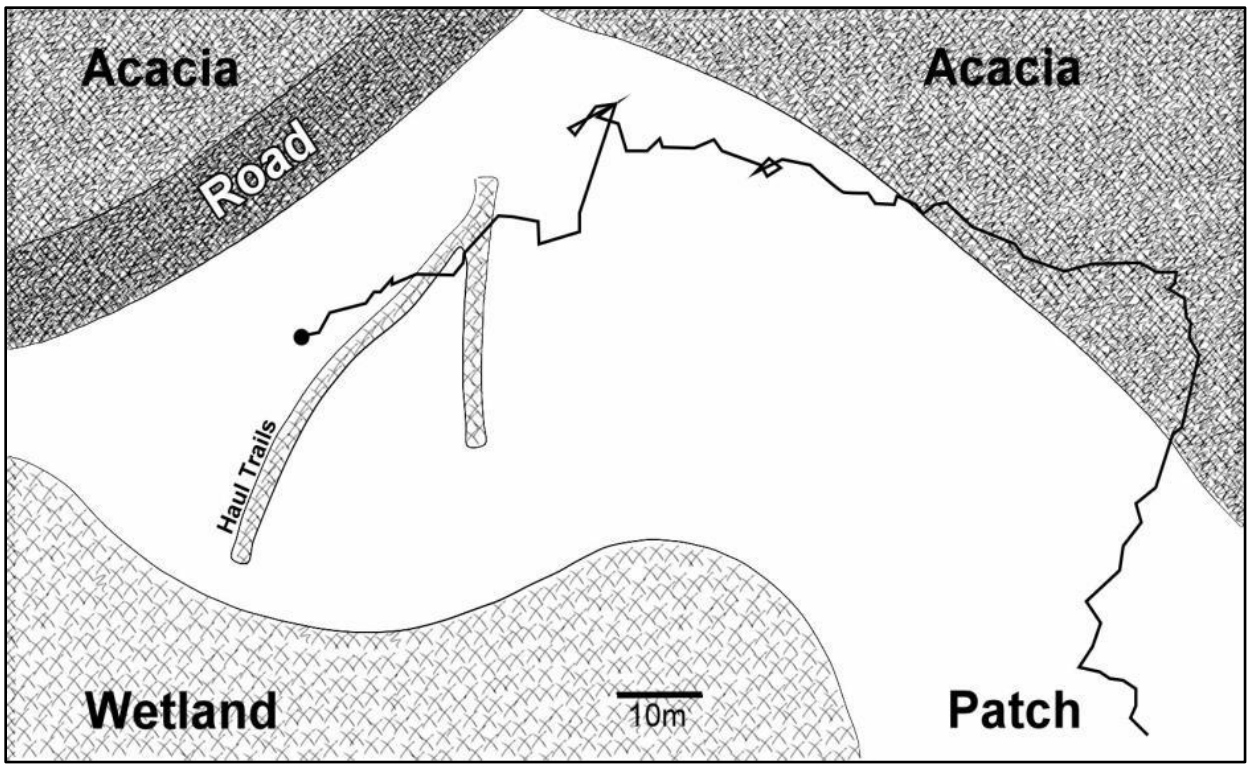


Figure 3.7: Painted treeshrew *(Tupaia picta)* (TPIC4/07) movement trajectory in T1A forest patch showing behaviour at edges (•= point of release).

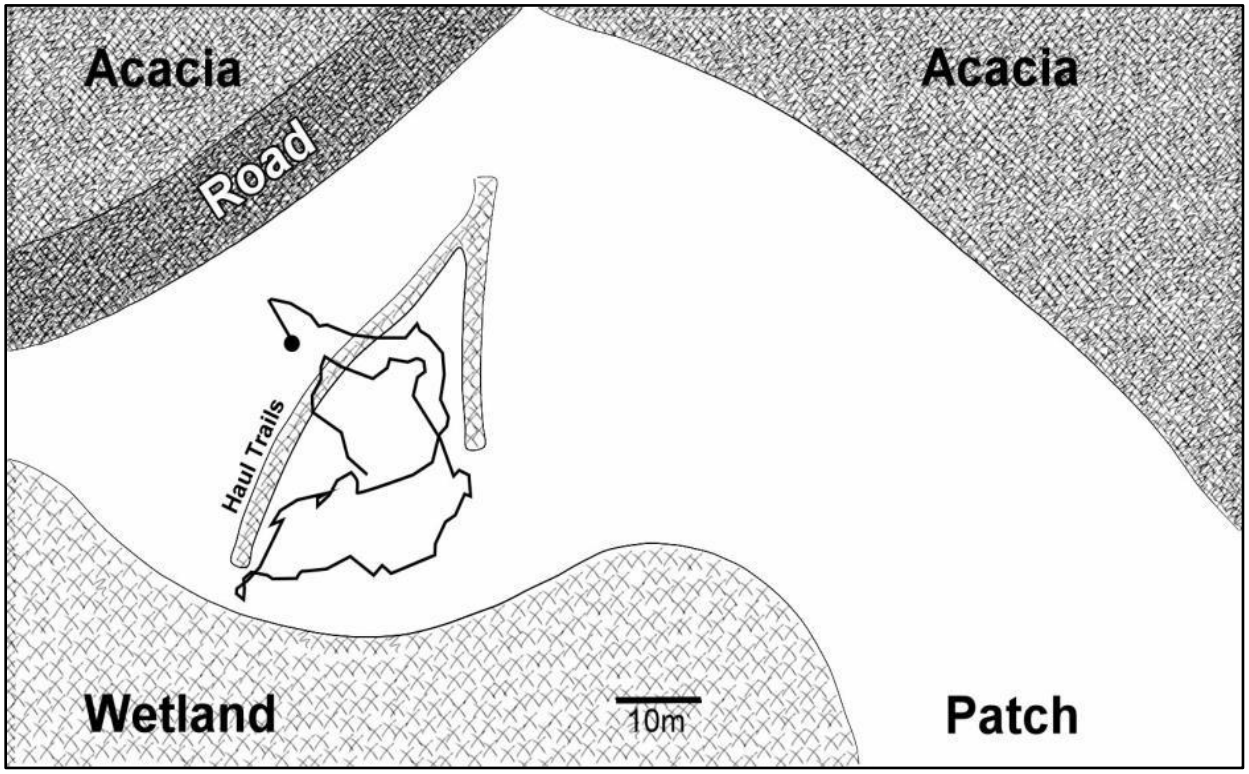


Figure 3.8: Painted treeshrew *(Tupaia picta)* (TPIC5/07) movement trajectory in T1A forest patch showing behaviour at edges (•= point of release).

The movement orientation of animals released at the T1A forest patch was found to differ significantly between eight 45^{o} directional segments (ANOVA P = 0.014), and animals were observed to move in a general direction away from the main forest road located in the northwest quadrant. Tukey's pair-wise comparisons found the number of movements between 90^{o} and 135^{o} heading away from the road was significantly greater than those in the 270^{o} – 315^{o} and 315^{o} – 360^{o} segments facing the road. Figures 3.9 & 3.10 illustrate a clear selection in movement orientation to the southeast along the alignment of the patch.

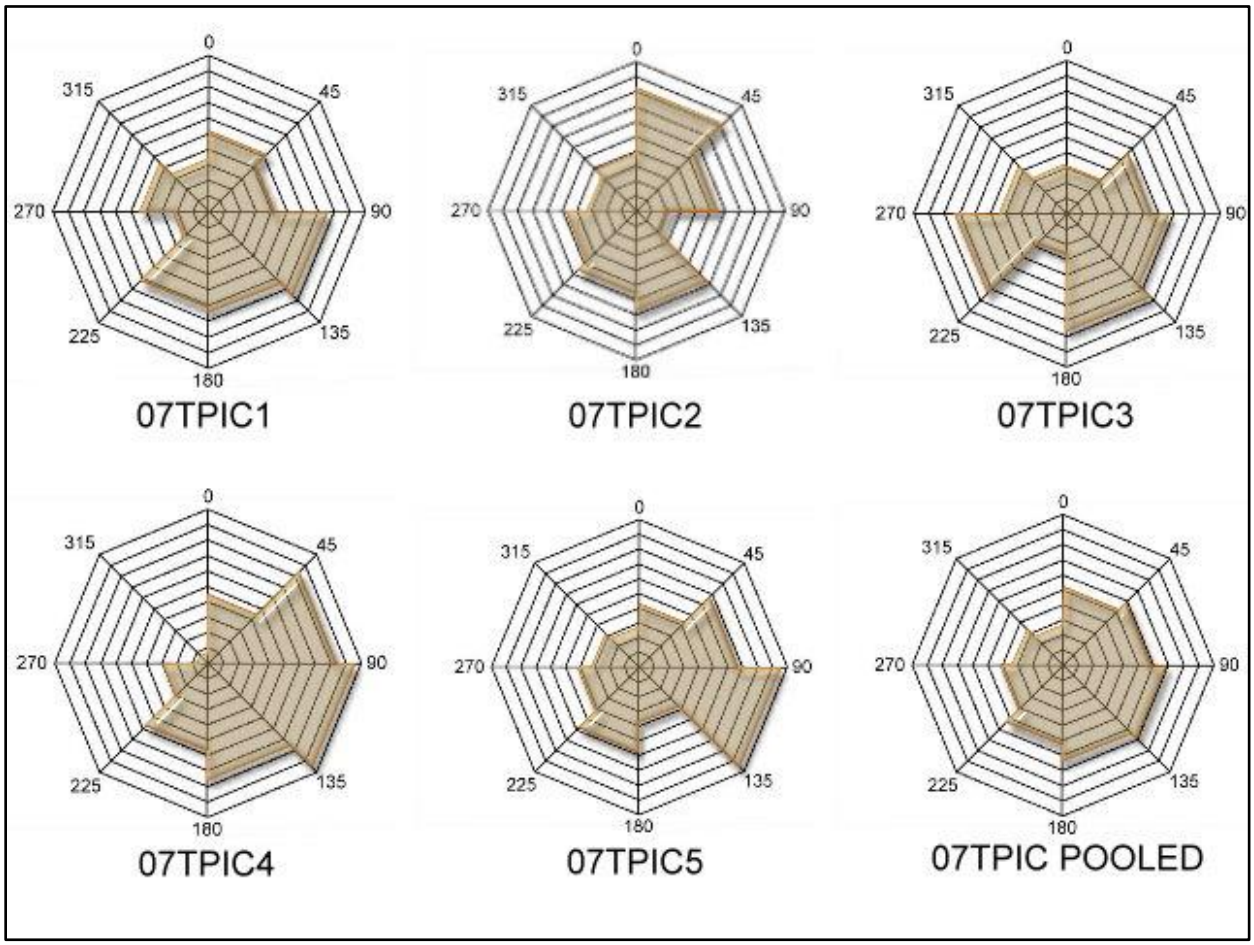


Figure 3.9: Compass plots of five painted treeshrew *(Tupaia picta)* movement trajectories at the TIA forest patch, Planted Forest Zone, Sarawak, East Malaysia, showing movement away from forest road located in northwest quadrant. Graduations on compass plots represent 2.5% increments.

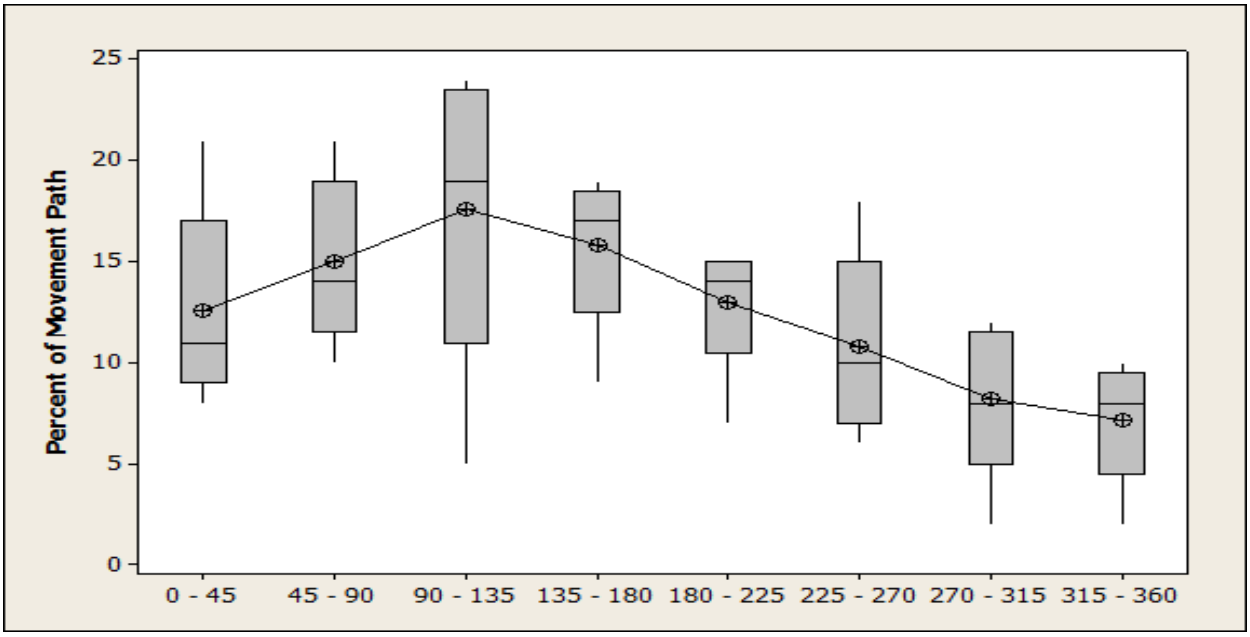


Figure 3.10: Box plot of painted treeshrew *(Tupaia picta)* movement orientation in a novel patch in the Planted Forest Zone, Sarawak, East Malaysia. Forest road is located between 270° and 360° on the bottom axis.

Use of Substrate: In novel patches painted treeshrews spent most of their time on the ground (Table 3.5). Step lengths associated with logs, branches and on the ground were found to differ significantly (ANOVA; P = 0.004), and pair-wise Tukey's tests revealed movement on logs entailed significantly longer movements than both those performed on the ground and on branches. Where movement was associated with logs, step lengths were significantly greater compared with step lengths on the ground (t-test, t = -2.99, P = 0.014). Step lengths recorded in low branches of trees had a pooled mean length significantly shorter than those recorded on logs (t-test, t = 2.99, P = 0.012), but not significantly different from step lengths on the ground. Where painted treeshrews crossed haul trails, their mean step lengths within the haul trail area were found to be significantly longer (mean 2.36 m) than the overall mean step lengths on the ground (Paired t-test; t = -3.03, P = 0.029).

In home territories painted treeshrews also spent most of their time on the ground. Mean step lengths associated with logs, branches and on the ground were found to differ significantly

(ANOVA; P = 0.006). Two sample t-tests revealed significantly longer step lengths on or associated with logs than those observed on the ground (t-test; t = -2.90, P = 0.023), and also significantly longer step lengths on logs compared with branches (t-test; t = 2.92, P = 0.017). No significant difference was detected between step lengths on the ground and on branches.

Four animals released into novel patches were recorded making short climbing movements with a mean height of 1.47 m above ground. One individual (TPIC2/07) made four individual ascents of 1.00 m, 1.50 m, 1.20 m, and 4.50 m in height respectively. All other above ground movements attained heights of approximately 1.00 m each. In home territories, above ground movement was recorded in three individuals. TPIC4/10 made five individual climbs; none exceeding 1.00 m. TPIC6/10 made two climbs to 1.00 m, and TPIC7/10 made one ascent to1.5 m and two accents to 1.00 m above ground on low branches.

Path Tortuosity: The D Mean for animals released at their points of capture (Mean 1.1254) were significantly less tortuous than those released in novel patches (Mean 1.3424) (t-test; t = 2.39, P = 0.038). No differences in tortuosity were detected between sexes.

Flight Response: In novel patches six animals were recorded seeking first protective cover within the first 100.00 m following release. Distances ranged from 10.70m to 54.00 m (mean 37.25 m), and included cover beneath logs (n = 3), subterranean cavities (n = 2), and in hollow tree stumps (n = 1). In home territories seven individuals were recorded seeking first protective cover within the first 100.00 m following release. Distances ranged from 15.00 m to 71.20 m (mean 39.01 m), and included cover beneath logs (n = 2), subterranean cavities (n = 2), and in hollow tree stumps and logs (n = 3).

Table 3.5: Substrate use and Mean Fractal Dimension (D Mean) of painted treeshrews *(Tupaia picta)* released in novel patches and home territories. Distance = total tracked distance tracked; % Route (G = Ground) (L = Log) (B = Branch) = percent of total route on or associated the respective substrates; StLG = mean step-length on ground; StLg = mean step-length on or associated with logs, and StLB = mean step length on branches.

Animal	Site	Distance	% G	% L	% B	StL G	StL L	StL B	D Mean
Novel Patch									
TPIC1/06 (F)	Sg. Mina	98.50 m	78.80%	21.20%	0.00%	2.91 m	3.75 m	NA	1.0860
TPIC2/07 (F)	Samarakan	184.90 m	95.95%	1.79%	2.26%	1.59 m	1.03 m	0.98 m	1.5667
TPIC3/07 (F)	Samarakan	234.80 m	92.08%	5.61%	2.09%	1.97 m	4.20 m	1.57 m	1.7242
TPIC4 /07(F)	Samarakan	215.50 m	92.12%	6.38%	1.50%	2.05 m	2.13 m	3.00 m	1.5648
TPIC5/07 (M)	Samarakan	238.00 m	88.53%	10.27%	1.20%	2.12 m	4.62 m	1.35 m	1.1111
TPIC6/07 (M)	Samarakan	167.60 m	93.20%	3.37%	3.43%	1.88 m	2.65 m	1.35 m	1.7601
TPIC7/07 (M)	Kelawit	223.30 m	87.95%	12.05%	0.00%	2.27 m	4.25 m	NA	1.3484
TPIC8/07 (M)	Kelawit	61.90 m	71.71%	22.29%	0.00%	1.13 m	5.35 m	NA	1.0487
TPIC9/10 (M)	Samarakan	43.00 m	100.00%	0.00%	0.00%	1.13 m	NA	NA	1.1195
TPIC10/10 (F)	Samarakan	116.20 m	95.01%	4.99%	0.00%	2.12 m	2.50 m	NA	1.0948
Mean		**158.47 m**	**90.14%**	**8.80%**	**1.05%**	**1.91 m**	**3.34 m**	**1.65 m**	**1.3424**
Median		**141.90**	**92.10%**	**6.00%**	**1.03%**	**1.94 m**	**3.34 m**	**1.46**	**1.2340**
Home Territory									
TPIC1/06 (F)	Samarakan	71.20 m	25.40%	59.40%	15.20%	1.66 m	2.23 m	1.80 m	1.2616
TPIC2/10 (M)	Samarakan	60.10 m	68.39%	31.61%	0.00%	1.52 m	2.71 m	NA	1.1362
TPIC4/10 (M)	Samarakan	69.80 m	91.40%	8.60%	0.00%	1.82 m	6.0 m	NA	1.0432
TPIC5/10 (F)	Samarakan	188.60 m	91.33%	6.49%	2.18%	1.39 m	4.04 m	0.82 m	1.0922
TPIC6/10 (M)	Samarakan	219.70 m	97.13%	2.87%	0.00%	1.78 m	1.58 m	NA	1.1021
TPIC7/10 (M)	Samarakan	188.10 m	86.12%	12.97%	0.90%	1.23 m	3.03 m	0.85 m	1.2288
TPIC8/10 (M)	Samarakan	116.00 m	82.67%	13.97%	3.36%	1.36 m	3.28 m	1.95 m	1.0466
TPIC9/10 (F)	Samarakan	117.10 m	100.00%	0.00%	0.00%	2.13 m	NA	NA	1.0927
Mean		**128.83 m**	**80.31%**	**16.86%**	**2.71%**	**1.61 m**	**3.27 m**	**1.36 m**	1.1254
Median		**116.55 m**	**88.89%**	**10.79%**	**0.45%**	**1.59 m**	**3.03 m**	**1.33 m**	**1.1021**

In novel patches pooled mean step lengths of painted treeshrews moving on the ground were observed to increase with distance from the point of release (r square = 62.9%). However in home territories a negative correlation was detected between mean step lengths on the ground and distance from the point of release (r square = 56.7%) over the entire lengths of paths (See Figure 3.11).

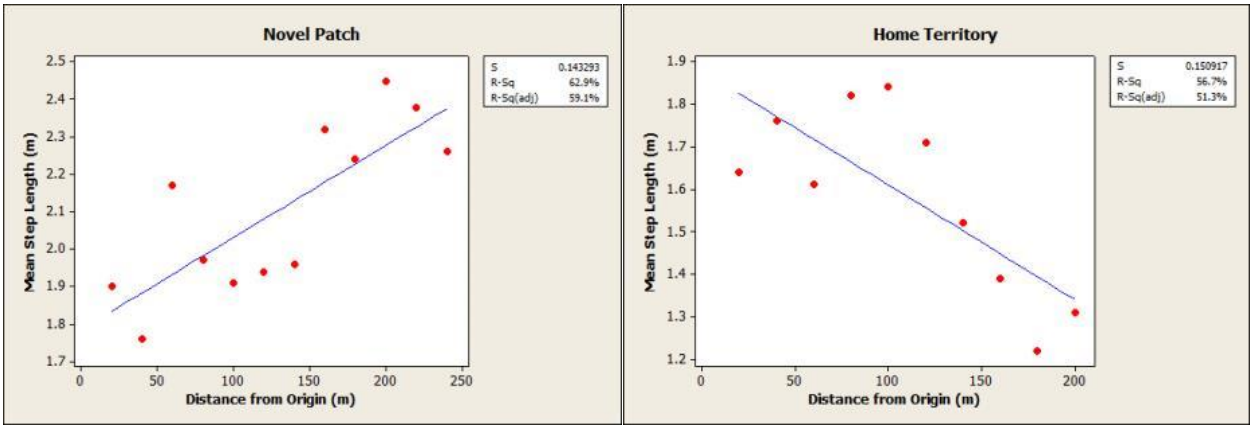


Figure 3.11: Scatter plots of painted treeshrew *(Tupaia picta)* step lengths on the ground in relation to distance travelled from points of release in novel patches (left) and home territories (right).

In novel patches the pooled mean turning angle for *T. picta* was 51.22^{o}, (43^{o} – 62^{o}; median 39.56^{o}). The mean turning angle per step showed no significant positive or negative correlation over the entire lengths of the pooled animal paths with each consecutive step from point of release. However the pooled mean of the initial 50 turning angles, within which a flight response immediately post-release should be detectable, showed positive correlation (r square = 41.0%) where angles were shown to increase with distance moved away from the origin (Figure 3.12).

In home territories the pooled mean of turning angles for *T. picta* was 52.00^{o}, (37^{o} – 70^{o}; Median 38.67^{o}). Mean turning angles of the pooled sample were also not found to be correlated with distance from the origin, however slight positive correlation with distance was observed for

turning angles within the first fifty steps (r square = 9.7%) (Figure 3.12) where turning angle was observed to increase with distance travelled.

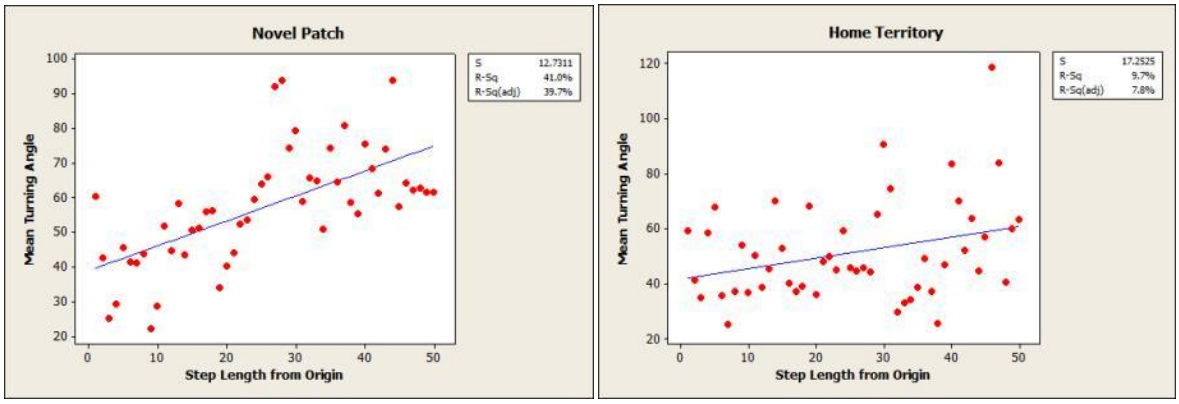


Figure 3.12: Fitted line plot of mean turning angle for painted treeshrews *(Tupaia picta)* by distance from origin within first fifty step lengths in novel patches (left) and home territories (right).

3.3.3 Large Treeshrew *(Tupaia tana)*

Five male and four female *T. tana* were tracked over a total distance of 1526.70m in novel patches. Just one female; TTAN01/06 was released at its point of capture in Samarakan Conservation Forest during the pilot study on 10th July 2006. This animal was tracked for a distance of 244.00 m, but unfortunately the raw data from this individual was lost. However field notes taken at the time record the mean step length, substrate use and other habitat use data.

Response to Edge: Eight of the nine tracked *T. tana* released in novel patches encountered a combined total of 33 habitat edges (See Table 3.6). Of the 12 encounters with riparian edges, the two individuals (TTAN3/07 & TTAN5/10) that made movements across the riparian edge both moved across open water. Animal TTAN3/03 moved in the open on emergent grasses growing in an open wetland for a distance of >5.0 m before returning to the forest patch, however due to the depth of water the path could not be accurately tracked. During the animal's movement into the

wetland area the nylon thread was observed to enter open water free of any supportive structures such as tall grasses or overhanging branches etc and it was therefore determined that the animal had entered the water for an unknown distance.

Similarly, the movement path of animal TTAN5/10 was observed to move out on a low hanging branch perpendicular with the edge of the patch over standing water. The thread was observed to extend into open water and could no longer be tracked, again on account of water depth. An extensive search of the immediately surrounding forest patch failed to detect TTAN5/10 returning to land.

Table 3.6: Response to edge features encountered by large treeshrews *(Tupaia tana)*. CROSS = animal crossed over edge feature; NCParallel = animal moved parallel along feature without crossing; NCAway = animal moved away from edge feature without crossing; NCPooled = NCParallel + NCAway. Numbers in parenthesis ( ) indicate number of individuals contributing to responses.

Response	Road	Haul Trail	Acacia	Riparian	Clearing	Total
CROSS	0	5(3)	0	2(2)	0	7
NCParallel	4(3)	3(2)	2(2)	6(4)	2(2)	17
NCAway	3(3)	0	2(2)	4(2)	0	9
NCPooled	7	3	4	10	2	26
Total	**7**	**8**	**4**	**12**	**2**	**33**

Use of Substrate: In novel patches large treeshrews spent most of their time on the ground (Table 3.7). Where movement was associated with logs, step lengths were found to be greater compared on the ground (t-test, t = -2.54, P = 0.025). Step lengths recorded in low branches of trees were not found to differ significantly in length from those recorded on the ground or those associated with logs.

Although raw data from the individual released in its home territory in 2006 was lost, field notes record the mean step length for this individual as 5.10 m, and also that the individual made several long straight movements of 17.90 m, 12.60 m, 11.70 m. 11.10 m and 8.80 m throughout the length of the movement path.

Table 3.7: Substrate use and Mean Fractal Dimension (D Mean) of large treeshrews *(Tupaia tana)* released in novel patches and home territories. Distance = total tracked distance tracked; % Route (G = Ground) (L = Log) (B = Branch) = percent of total route on or associated the respective substrates; StLG = mean step-length on ground; StLg = mean step-length on or associated with logs, and StLB = mean step length on branches.

Animal	Site	Distance	% G	% L	% B	StL G	StL L	StL B	D Mean
Novel Patch									
TTAN1/07 (M)	Samarakan	53.8 m	81.09%	18.91%	0.00%	2.90 m	3.65 m	NA	1.5055
TTAN2/07 (F)	Samarakan	189.00 m	69.89%	19.92%	6.16%	2.48 m	1.38 m	1.53 m	1.3424
TTAN3/07 (F)	Samarakan	233.50 m	93.80%	6.20%	0.00%	2.07 m	3.43 m	NA	1.4419
TTAN4/07 (M)	Kelawit	234.00 m	91.42%	8.58%	0.00%	1.80 m	3.74 m	NA	1.1994
TTAN1/10 (F)	Samarakan	235.70 m	94.17%	5.83%	0.00%	1.39 m	2.52 m	NA	1.3452
TTAN2/10 (F)	Samarakan	231.60 m	87.72%	11.05%	1.50%	1.69 m	2.90 m	3.30 m	1.4112
TTAN3/10 (M)	Samarakan	125.00 m	78.50%	21.50%	0.00%	1.39 m	2.70 m	NA	1.2560
TTAN4/10 (M)	Samarakan	48.10 m	96.71%	3.29%	0.00%	1.07 m	1.20 m	NA	1.2114
TTAN5/10 (M)	Samarakan	176.00 m	62.95%	15.53%	21.20%	1.35 m	2.90 m	0.92 m	1.4332
Mean		**169.63 m**	**84.03%**	**12.31%**	**3.21%**	**1.79 m**	**2.71 m**	**1.92 m**	1.3501
Median		**189.90 m**	**87.72%**	**11.05%**	**0.00%**	**1.69 m**	**2.90 m**	**1.52 m**	**1.3452**
Home Territory									
TTAN1/06 (F)		**244.00 m**	**82.40%**	**17.00%**	**0.60%**	**-**	**-**	**-**	**-**

In novel patches three animals were recorded making ascents into low branches (n = 7) with a mean height of 1.61 m above ground. One individual (TTAN1/07) made three ascents of 2.00 m, 1.00 m, and 1.00 m above ground level respectively. Animal TTAN9/10 also made three discrete ascents of 1.50 m, 1.00 m and 1.75 m, while TTAN6/10 made a single climbing movement,

attaining a height of 3.00 m above ground level. No records were made of TTAN1/06 making above ground movements except for at a nest/den site (see below).

Flight Response: Pooled mean step lengths of *T. tana* on the ground were not found to be correlated with distance from the point of release, with no individuals means exhibiting either positive or negative correlations with distance. Pooled mean turning angle for *T. tana* was 51.25^{o}, ($33^{o} – 83^{o}$; median 39.88^{o}), and angles were not found to be correlated with distance from origin over the both the entire length of the paths, or over the initial 50 step lengths.

Five individuals were recorded seeking first protective cover within the first 100.00 m following release. Distances ranged from 23.30 m to 53.80 m (mean 36.26 m), and included cover beneath logs (n = 3), in root hollows (n = 1) and in subterranean cavities (n = 1).

Nest Site Location: For the female TTAN01/06, released at its point of capture in Samarakan Forest in 2006, at 166.00 m from the point of release, the nylon thread disappeared into nest/den constructed from woven wood fibres surrounded by leaves. The nest was located approximately 1.20 m above ground level on top of a termite nest, amongst aerial roots of a large tree with a breast height diameter (DBH) of approximately 750 mm. The thread reappeared again from the same opening and continues for a further 78.00 m before the empty spool case was recovered.

3.3.4 Brown Spiny Rat *(Maxomys rajah)*

Six female and nine male brown spiny rats were tracked in novel patches (Shadbolt and Ragai 2010). An additional male *M. rajah* was tracked for a distance of just 8.60 m from the point of release before entering a subterranean burrow where the nylon thread ended. Data from this animal is therefore only used in reference to distance travelled to first use of protective cover.

In 2009 and 2010 seven male and five female brown spiny rats were trapped and released at their respective points of capture. Of these, two individuals (MRAJ1/09 and MRAJ2/09) were caught and released in small forest patches within acacia compartments, and their responses to edge is also be discussed here but not analysed as part of the dataset for animals released in novel patches.

Response to Edge: Brown spiny rats encountered roads on 11 occasions, haul roads on 14, acacia on 16, wetland/riparian areas on four occasions, and large clearings on six occasions (Table 3.8; Shadbolt and Ragai 2010). As discussed above, two animals (MRAJ1/09 and MRAJ2/09) were captured and released within a small forest patches within mature (5 – 6 year old) acacia plantation compartments. MRAJ1/09 was released at its point of capture near the edge of the acacia compartment. The animal came within 5.00 m of the acacia edge, at which point it made a distinct change in direction and moved parallel with the acacia edge for 15.30 m before heading back into the forest patch again. At 64.10 m the nylon thread disappeared into a well-worn, perfectly symmetrical 45 mm diameter subterranean tunnel. Despite being released within an isolated forest patch, MRAJ2/09 did not encounter any acacia compartment edges. At 19.30 m from its point of release, MRAJ2/09 entered a subterranean burrow from which approximately 1.30 m of thread was retrieved, and at 68.50 m the animal returned once again to the same burrow.

Table 3.8: Response to edge features encountered by brown spiny rats *(Maxomys rajah)*. CROSS = animal crossed over edge feature; NCParallel = animal moved parallel along feature without crossing; NCAway = animal moved away from edge feature without crossing; NCPooled = NCParallel + NCAway. Numbers in parenthesis ( ) indicate number of individuals contributing to responses (Source: Shadbolt and Ragai 2010).

Response	Road	Haul Trail	Acacia	Riparian	Clearing	Total
CROSS	1(1)	7(4)	3(3)	1(1)	0	13
NCParallel	4(4)	5(3)	6(4)	2(2)	2(2)	18
NCAway	6(5)	2(2)	7(5)	1(1)	4(4)	20
NCPooled	10	7	12	3	6	38
Total	**11**	**14**	**16**	**4**	**6**	**51**

Use of Substrate: In novel patches brown spiny rats spent most of their time on the ground (Table 3.9). Where movement was associated with logs step lengths were generally greater than on the ground. (t-test: $P = 0.0015$, df = 14). No movement paths of *M. rajah* were recorded above ground level in the low branches of trees or suspended woody debris apart from logs and branches at ground level.

In home territories brown spiny rats also spent most of their time on the ground (Table 3.10). Where movement was associated with logs mean step lengths were also greater than those on the ground (t-test: $P = 0.0019$, df = 11).

Table 3.9: Substrate use and Mean Fractal Dimension (D Mean) of brown spiny rats *(Maxomys rajah)* released in novel patches. Distance = total tracked distance tracked; % Route (G = Ground) (L = Log) (B = Branch) = percent of total route on or associated the respective substrates; StLG = mean step-length on ground; StLg = mean step-length on or associated with logs, and StLB = mean step length on branches (Source: Shadbolt and Ragai 2010).

Animal	Site	Distance	% G	% L	% B	StL G	StL L	StL B	D Mean
Novel Patch									
MRAJ1/07 (M)	Kalabat	210.00 m	57.90%	42.10%	0.00%	2.34 m	4.43 m	NA	1.7281
MRAJ2/07 (M)	Kalabat	175.50 m	83.90%	16.10%	0.00%	2.68 m	3.13 m	NA	1.1547
MRAJ3/07 (M)	Kalabat	147.10 m	88.58%	9.20%	0.00%	1.92 m	2.70 m	NA	1.5874
MRAJ4/07 (M)	Kalabat	231.00 m	97.10%	2.90%	0.00%	1.60 m	1.65 m	NA	1.3913
MRAJ5/07 (F)	Samarakan	157.00 m	65.80%	34.20%	0.00%	1.67 m	2.98 m	NA	1.6628
MRAJ6/07 (F)	Tubau	227.30 m	96.00%	4.00%	0.00%	2.16 m	4.50 m	NA	1.5051
MRAJ7/07 (M)	Tubau	147.80 m	92.20%	7.80%	0.00%	1.87 m	2.32 m	NA	1.3074
MRAJ8/07 (F)	Tubau	100.00 m	98.80%	1.20%	0.00%	2.02 m	1.20 m	NA	1.3417
MRAJ9/07 (M)	Tubau	42.30 m	76.80%	23.20%	0.00%	1.63 m	2.45 m	NA	1.1235
MRAJ10/07 (F)	Tubau	103.60 m	82.40%	17.60%	0.00%	1.62 m	3.03 m	NA	1.0616
MRAJ11/07 (M)	Tubau	233.00 m	98.00%	2.00%	0.00%	1.60 m	1.20 m	NA	1.3935
MRAJ12/07 (M)	Kelawit	211.00 m	97.20%	2.80%	0.00%	2.60 m	5.05 m	NA	1.4617
MRAJ13/07 (M)	Kelawit	104.00 m	98.10%	1.90%	0.00%	1.64 m	2.00 m	NA	1.2161
MRAJ14/07 (F)	Kelawit	229.30 m	87.90%	12.10%	0.00%	1.68 m	3.48 m	NA	1.2821
MRAJ15/07 (F)	Kelawit	245.10 m	95.20%	4.80%	0.00%	1.44 m	1.95 m	NA	1.7528
Mean		**166.60 m**	**87.60%**	**12.25%**	**0.00%**	**1.90 m**	**2.80 m**	**NA**	**1.4647**
Median		**175.50 m**	**95.20%**	**7.80%**	**0.00%**	**1.68 m**	**2.70 m**	**NA**	**1.3924**

Path Tortuosity: In novel patches D Mean for 13 animals ranged from 1.0616 to 1.5294 (Mean1.4647). In home territories D Mean ranged from 1.1184 to 1.7236 (Mean 1.3826). D Means for animals released at their points of capture were not found to differ from those released in novel patches, and no differences were detected between sexes.

Table 3.10: Substrate use and Mean Fractal Dimension (D Mean) of brown spiny rats *(Maxomys rajah)* released in home territories. Distance = total tracked distance tracked; % Route (G = Ground) (L = Log) (B = Branch) = percent of total route on or associated the respective substrates; StLG = mean step-length on ground; StLg = mean step-length on or associated with logs, and StLB = mean step length on branches.

Animal	Site	Distance	% G	% L	% B	StL G	StL L	StL B	D Mean
MRAJ1/09 (M)	Kapur 1	64.10 m	100%	0.00%	0.00%	1.30 m	NA	NA	1.2420
MRAJ2/09 (F)	Kapur 2	230.80 m	81.01%	18.48%	0.50%	1.08 m	2.38 m	1.1 m	1.3761
MRAJ1/10 (M)	Samarakan	110.80 m	94.91%	5.09%	0.00%	1.15 m	1.02 m	NA	1.1373
MRAJ2/10 (M)	Samarakan	224.60 m	90.90%	9.10%	0.00%	1.52 m	2.13 m	NA	1.2880
MRAJ3/10 (M)	Samarakan	213.40 m	95.08%	4.92%	0.00%	1.28 m	1.67 m	NA	1.2928
MRAJ4/10 (M)	Samarakan	74.00 m	83.28%	15.30%	1.42%	1.60 m	1.65 m	0.90 m	1.3749
MRAJ5/10 (F)	Samarakan	55.90 m	82.35%	17.65%	0.00%	1.15 m	4.05 m	NA	1.3030
MRAJ6/10 (F)	Samarakan	121.00 m	97.22%	2.78%	0.00%	1.28 m	1.55 m	NA	1.6416
MRAJ7/10 (M)	Samarakan	115.10 m	98.42%	1.58%	0.00%	1.09 m	1.60 m	NA	1.3774
MRAJ8/10 (F)	Samarakan	43.10 m	93.81%	6.19%	0.00%	0.76 m	2.00 m	NA	1.7236
MRAJ9/10 (M)	Samarakan	79.20 m	84.25%	15.75%	0.00%	1.30 m	2.18 m	NA	1.1184
MRAJ10/10(F)	Samarakan	110.80 m	94.91%	5.09%	0.00%	1.15 m	1.02 m	NA	1.4810
Mean		**144.28 m**	**91.35%**	**8.49%**	**0.16%**	**1.22 m**	**1.93 m**	**1.0 m**	**1.3826**
Median		**110.80 m**	**94.36%**	**5.64%**	**0.00%**	**1.22 m**	**1.84 m**	**1.0 m**	**1.3390**

Flight Response: The pooled mean step lengths of *M. rajah* moving on the ground in novel patches and in home territories were not found to be correlated with distance from the point of release. In novel patches the pooled mean turning angle was 54.40^{o}, (27^{o} – 75^{o}; median 48.70^{o}). Here the mean of turning angles per step showed a negative correlation over the entire lengths of the pooled animal paths with each consecutive step from point of release (r square = 5.5%). However the pooled mean of the initial 50 turning angles showed a positive correlation (r square = 14.2%) where angles were shown to increase with distance moved away from the origin (Figure 3.13).

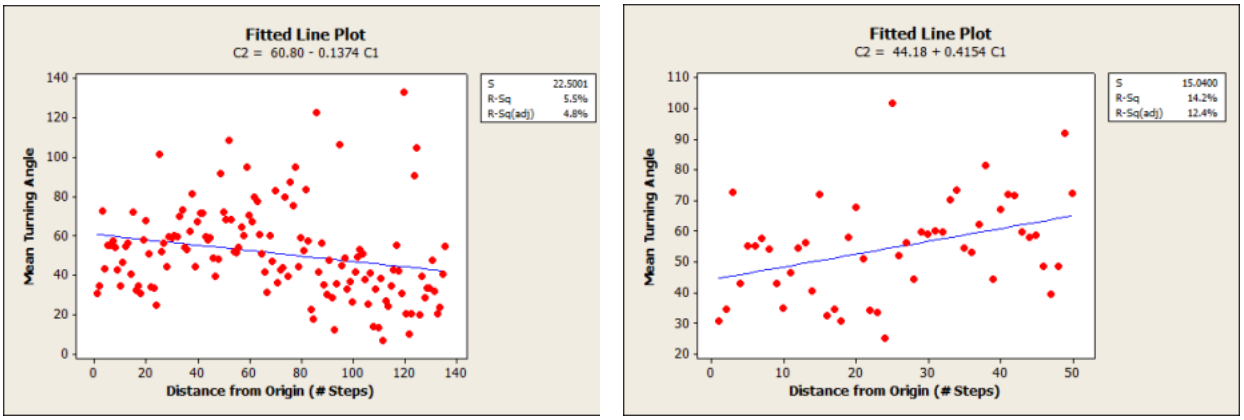


Figure 3.13: Scatter plot of brown spiny rat *(Maxomys rajah)* mean turning angle in relation to distance travelled from points of release across whole tracked distance (left), and within first fifty step lengths in novel patches (right).

In home territories the mean turning angle was 47.00^{o} (10.00^{o} – 99^{o}; median 44^{o}) and was not found to correlate with distance from origin across the entire lengths of the paths. However a slight negative correlation where turning angle decreased with distance was detected across the first 50 step lengths (r square = 6.9%).

Nine individuals were recorded seeking first protective cover within the first 100.00 m following release in novel patches. Distances ranged from 8.60 m to 31.80 m (mean 19.71 m), and included cover beneath logs (n = 4), in subterranean cavities (n = 2), eroded trenches (n = 2), and within hollow tree stumps (n = 1). In home territories seven individuals used protective cover within 100.00 m of release, with distances ranging from 11.40 m to 64.10 m (Mean 40.03 m) including beneath logs (n = 2), in subterranean cavities (n = 4), and within a root tangle (n = 1).

3.3.5 Mueller's Rat (*Sundamys muelleri)*

Five male Muller's rats were tracked over a total distance of 706.40 m. A sixth animal; SMUE2/07 (Female) was tracked for a distance of just 11.20m before it could no longer be tracked, however data for this path will be used for discussion of climbing movements above ground only. No animals were released within their home territories.

Response to Edge: Three animals encountered riparian margins on ten occasions (Refer Figure 3.11). SMUE6/07 encountered acacia on a single occasion, and that encounter resulted in a parallel movement along the edge for a distance of approximately 20 m before re-entering the forest patch (Table 3.11).

Table 3.11: Response to edge features encountered by Mueller's rats *(Sundamys muelleri)*. CROSS = animal crossed over edge feature; NCParallel = animal moved parallel along feature without crossing; NCAway = animal moved away from edge feature without crossing; NCPooled = NCParallel + NCAway. Numbers in parenthesis ( ) indicate number of individuals contributing to responses.

Response	Road	Haul Trail	Acacia	Riparian	Clearing	Total
CROSS	0	0	0	2(1)	0	2
NCParallel	0	0	1(1)	6(3)	0	7
NCAway	0	0	0	2(1)	0	2
NCPooled	0	0	1	8	0	9
Total	**0**	**0**	**1**	**10**	**0**	**11**

Use of Substrate: Mueller's rats spent most of their time on the ground and only two animals were recorded using the low branches of trees (Table 3.12) Where movement was associated with logs, step lengths were found to be greater than those on the ground (t-test, t = -4.40, P = 0.012). The mean step length on branches was 1.46 m, however as all observations were based on the habit of a single animal, no statistical inferences were made. Of the individuals ascending into low branches of trees, one animal (SMUE6/07) made two discrete ascents of 1.00 m and 3.00 m respectively. The second animal (SMUE2/07) made a single ascent to a height of 3.00 m

above ground level within the first ten metres of release before the nylon thread snapped and could not be located again despite an extensive ground search.

Table 3.12: Substrate use and Mean Fractal Dimension (D Mean) of Muller's rats *(Sundamys mulleri)* released in novel patches. Distance = total tracked distance tracked; % Route (G = Ground) (L = Log) (B = Branch) = percent of total route on or associated the respective substrates; StLG = mean step-length on ground; StLg = mean step-length on or associated with logs, and StLB = mean step length on branches.

Animal	Site	Distance	% G	% L	% B	StL G	StL L	StL B	D Mean
Novel Patch									
SMUE1/07 (M)	Tubau	30.60 m	74.44%	25.56%	0.00%	1.22 m	2.30 m	NA	1.8412
SMUE3/07 (M)	Tubau	69.50 m	73.33%	26.67%	0.00%	1.34 m	3.90 m	NA	1.6774
SMUE4/07 (M)	Kelawit	240.40 m	93.75%	6.25%	0.00%	1.74 m	2.88 m	NA	1.3319
SMUE5/07 (M)	Kelawit	158.30 m	73.87%	26.13%	0.00%	1.33 m	3.86 m	NA	1.6106
SMUE6/07 (M)	Kelawit	207.60 m	86.98%	7.85%	5.17%	1.48 m	5.17 m	1.46 m	1.3341
Mean		**141.28 m**	**80.47%**	**18.49%**	**1.03%**	**1.42 m**	**3.62 m**	**1.46 m**	**1.5590**
Median		**113.90 m**	**74.44%**	**25.56%**	**0.00%**	**1.34 m**	**3.86 m**	**1.46 m**	**1.6106**

Flight Response: Pooled mean step lengths of *S. muelleri* moving on the ground were found to be positively correlated with distance from the point of release however this correlation was not found to be significant. Means of individuals ranged from a positive correlation to slightly negative.

The pooled mean turning angle for *S. mulleri* was 56.00^{o}, (47^{o} – 62^{o}; median 41.40^{o}). Angles were not found to be correlated with distance from origin over the entire length of the paths, however a negative correlation was observed over the first 50 step lengths (r square = 9.1) (Figure 3.14).

Five individuals (83.33%) were recorded seeking first protective cover within the first 100.00 m following release. Distances ranged from 4.60 m to 37.30 m (mean 17.00 m), and included cover beneath logs (n = 2), within hollow tree stumps (n = 2) and in eroded trenches (n = 1).

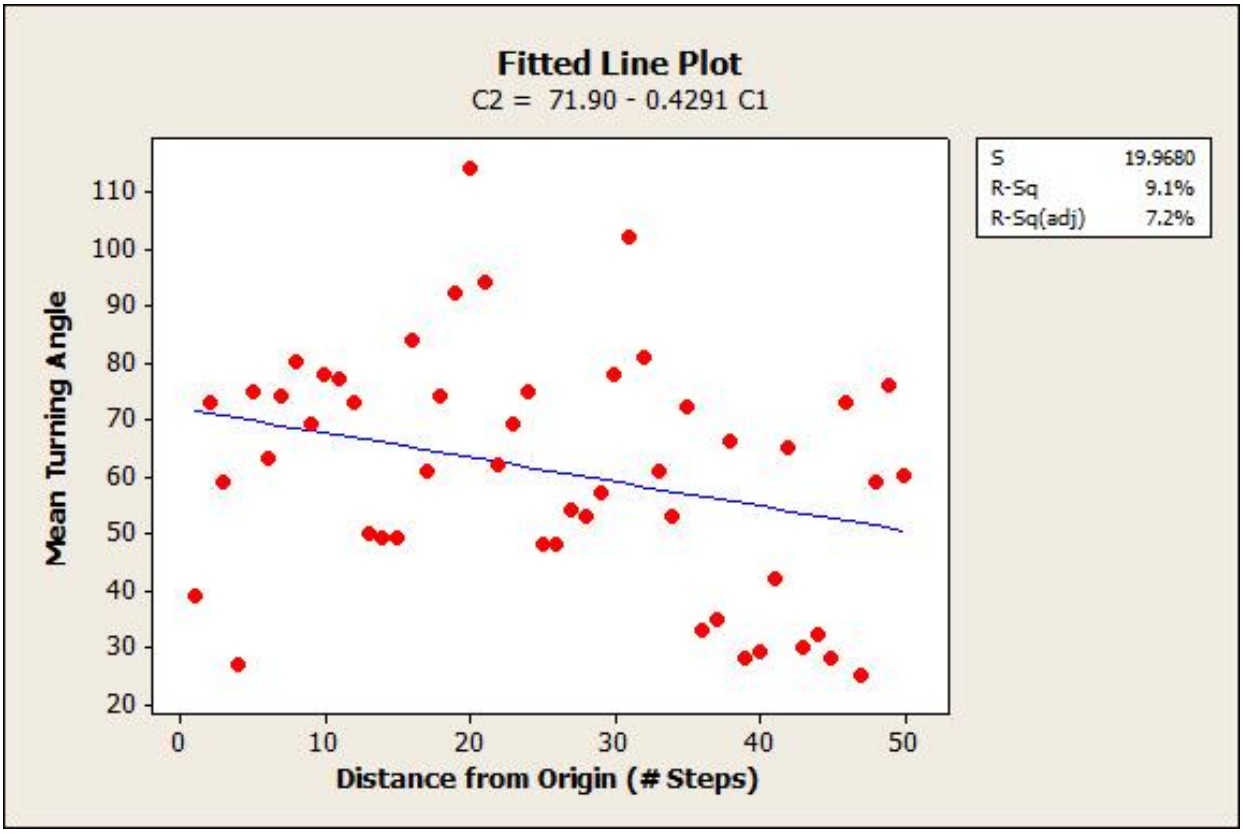


Figure 3.14: Fitted line plot of mean turning angle for Muellers rats *(Sundamys muelleri)* by distance from origin within first fifty step lengths in novel patches.

3.3.6 Long Tailed Giant Rat *(Leopoldamys sabanus)*

Two female long tailed giant rats were tracked over a total distance of 254.80m; LSAB1/07 (230 m) and LSAB2/07 (24.80 m). A third animal (LSAB3/07) escaped prior to a tracking spool being fitted, however the movement of this animal will be discussed in terms of its above ground movement only, and based on direct observations. No animals were released at their points of capture.

Response to Edge: LSAB1/07 encountered edge features on just two occasions: 1) at a large open clearing, and 2) at a small stream and open wetland area. Upon reaching the edge of the forest patch adjacent to the large open area, the animal ascended into the low branches of trees without crossing the edge. Here the animal climbed to a height of three metres, returned to the ground and then climbed again to a height of approximately ten meters before returning to ground level and moving back into the forest patch.

On encountering the edge at the stream (1.00 m wide x 0.25 m deep) and open wetland area, LSAB1/07 immediately crossed the stream and proceeded to move through and over tall dense grasses and ferns growing in the shallow standing water of the wetland. As it did so, the animal moved in long straight step lengths (mean 6.10 m; 3 m – 14.4 m) for approximately 20 m at which point the almost empty spool casing was recovered.

Use of Substrate: Animal LSAB1/07 was accurately tracked over a distance of 115 m. During its movement, the rat ascended on three occasions into the branches of trees to heights of 3.00 m, 10.00, and >10.00 m respectively and was therefore not able to be accurately tracked and recorded over much of this movement path. Inspection of the recovered spool revealed that approximately ten metres of thread still remained within the casing, indicating that a balance of approximately 115 m length of movement path was unrecorded in the branches of the sub canopy. Based on this, the animal was estimated to have spent 25.39% of its time on the ground, 5.43% on or associated with logs, and 52.91% in branches. The animal was also observed to move on tall grasses across an open wetland area, where it spent 10.61% of the total movement path on the vegetation and 0.52% across open water. Where step lengths of the animal were associated with logs, the mean step length was greater (mean 6.25 m) compared with on the

ground (mean 3.92 m) and in branches (mean 2.23 m) where these were able to be recorded. Just one movement (1.2 m) was recorded across open water.

LSAB2/07 was tracked for just 24.80m before the tracking spool detached. Over this distance all movements were made on the ground where the mean step length was 1.27 m (0.4 – 2.4 m). The third animal (LSAB3/07) that escaped before the tracking spool was fitted was observed to immediately climb to a height of approximately ten metres above ground level. The animal moved at speed vertically up the trunk of the nearest tree from the release point where it remained motionless in the crotch of a branch until after field staff had retreated from the forest patch (Figure 3.15).

Figure 3.15: Long-tailed tree rat *(Leopoldamys sabanus)* LSAB3/07 (circled) resting in a tree approximately ten metres above ground immediately following release (Photograph A. Shadbolt, 2007).

Flight Response: The mean of the pooled turning angles for *L. sabanus* was 59^{o} (55^{o} – 62^{o}; median 41^{o}). Due to the small number of step lengths for LSAB2/07 (n = 10) linear regression was performed for LSAB1/07 only in order to detect possible correlation between turning angle and distance from origin. No correlation was found for this animal.

3.3.7 Three-Striped Ground Squirrel (*Lariscus insignis)*

A single female three-striped ground squirrel (LINS1/07) was tracked over a total distance of 100.50 m at the novel patch near Samarakan, and four three-striped ground squirrels were trapped and released at their points of capture and tracked for a pooled distance of 696.70 m.

Response to Edge: LINS1/07 encountered a forest road on two occasions, and on both occasions this resulted in an immediate change in direction parallel with the edge before moving back into the patch. No other edge features were encountered.

Use of Substrate: Movement on the ground accounted for 94.66% of the animals' movement in the novel patch where the mean step length was 2.04 m, and a single movement on a log accounted for 5.34% of the tracked path where the step length was 4.80 m in length. LINS1/07 did not use branches during its movement, however was recorded to climb on a single occasion onto a termite nest at a height of 1.00 m above ground level.

In home territories animals also spent most of their movement path on the ground, and only two animals were recorded moving in branches. However while mean step lengths on branches represented the longest for the three substrates, these two individuals only used branches on a single occasion each (Table 3.13).

Flight Response: For LINS01/07 released in the novel patch, step lengths on the ground were positively correlated with distance from origin (r square = 10.1%), however no correlation was found between step length and distance from the origin within the first fifty metres of movement. Mean turning angle was 52^o (6^o – 160^o; median 35^o), and linear regression showed a negative correlation (r square = 18.6%) where turning angle decreased with distance from origin.

In home territories the pooled mean step lengths recorded on the ground increased in length with distance from origin (r square = 34.2%)**.** Mean turning angle was 49^o (15^o – 102^o; median 45^o) and was not correlated with distance from origin.

Table 3.13: Substrate use and Mean Fractal Dimension (D Mean) of three striped ground squirrels *(Lariscus insignis)* released in a novel patch and home territories. Distance = total tracked distance tracked; % Route (G = Ground) (L = Log) (B = Branch) = percent of total route on or associated the respective substrates; StLG = mean step-length on ground; StLg = mean step-length on or associated with logs, and StLB = mean step length on branches.

Animal	Site	Distance	% G	% L	% B	StL G	StL L	StL B	D Mean
Novel Patch									
LINS01/07	Samarakan	100.50 m	94.66 m	5.34%	0.00 %	2.04 m	4.80 m	NA	1.4551
Home Territory									
LINS01/10 (M)	Samarakan	161.20 m	94.30%	5.70%	0.00%	1.85 m	2.13 m	NA	1.6683
LINS02/10 (F)	Samarakan	222.50 m	95.09%	3.68%	1.23%	1.65 m	1.56 m	2.60 m	1.2935
LINS03/10 (M)	Samarakan	74.30 m	100.00%	0.00%	0.00%	1.77 m	NA	NA	1.3621
LINS04/10 (M)	Lana Road	238.70 m	82.84%	15.75%	1.41%	2.04 m	2.23 m	3.20 m	1.3944
Mean		**174.18 m**	**93.06%**	**6.28%**	**0.66%**	**1.83 m**	**1.97 m**	**2.90 m**	1.4296
Median		**191.85 m**	**94.70%**	**4.69%**	**0.62%**	**1.81 m**	**2.13 m**	**2.90 m**	**1.3783**

3.3.8 Species Comparisons

All species released into unfamiliar forest patches were found to have longer mean step lengths associated with logs than on the ground, with *T. picta, T. tana, M. rajah* and *S. mulleri* being significantly different. ANOVA detected no significant differences between the step-lengths of some species when moving on the ground. However while neither ANOVA nor Tukey's pair-wise comparisons detected significant differences, two-sample t-tests found step lengths on the ground for *T. longipes* (t = 2.69, df 7, *P* = 0.031), *T. picta* (t = 2.59, df 12, *P* = 0.024) and *M. rajah* (t = 3.61, df 14, P = 0.003) were significantly longer than those of *S. mulleri* (Figure 3.16).

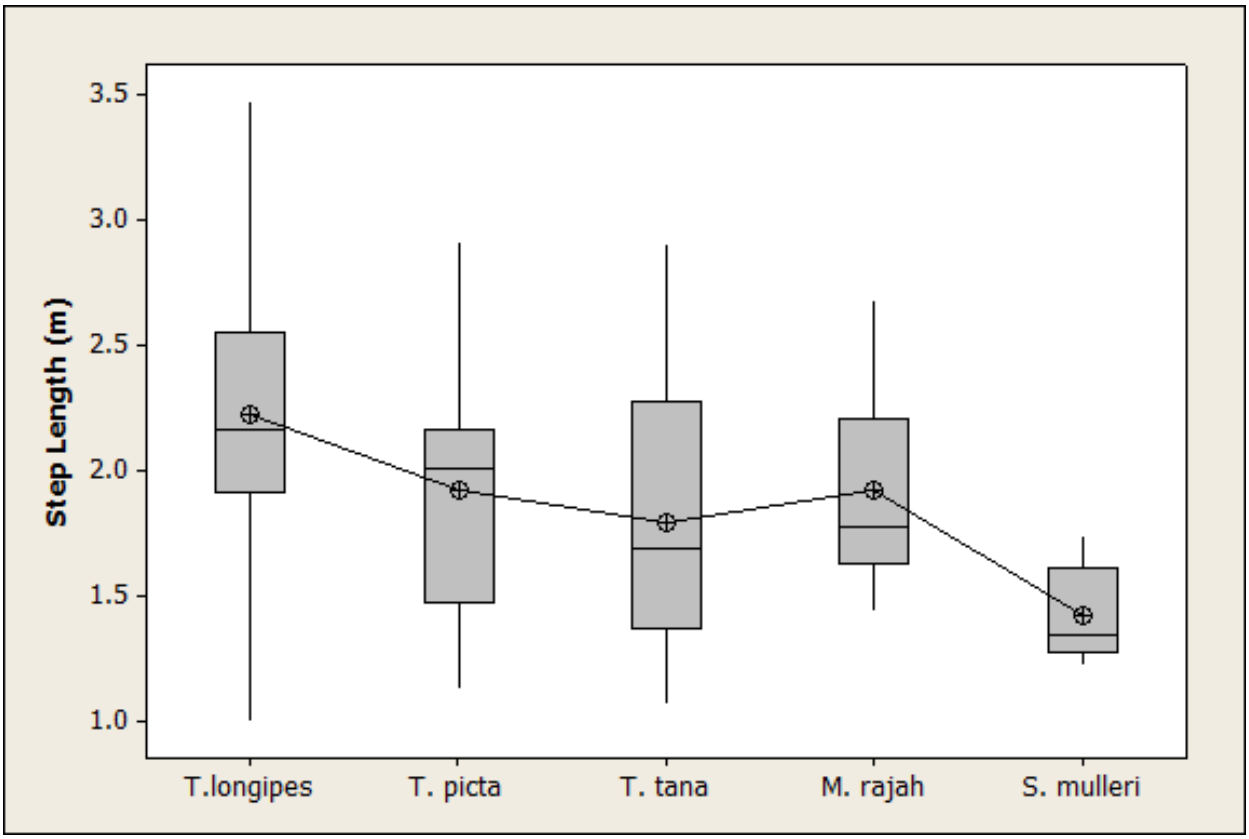


Figure 3.16: Box-plot of mean step lengths on the ground for five non-volant small mammal species released into novel patches in the Planted Forest Zone, Sarawak, East Malaysia (ANOVA; S = 0.5128, *P* = 0.149).

ANOVA detected no differences in D Mean between species released in novel patches, however significant differences were detected between species released at their points of capture (ANOVA; P = 0.005). Here the paths of *T. picta* were found to be significantly less tortuous than those of *M. rajah* (**t =** -3.99, df 16, P = 0.001), *T. longipes* (t = -8.90, df 7, P = <0.00), and *L. insignis* (t = -3.49, df 3, P = <0.040).

Mean distance travelled before protective cover was used within the first 100 m of movement differed significantly between four species from which data could be compared (Figure 3.17): *T. picta, T. tana, M. rajah* and *S. mulleri* (ANOVA; P = 0.012). Tukey's tests showed that both *T. picta* (n = 6; mean 37.25 m) and *T. tana* (n = 5; mean 36.26 m) travelled greater distances before seeking cover than *M. rajah* (n = 9; mean 19.71 m) and *S. muelleri* (n = 5; mean 17.00 m). Although not meeting the significance threshold, two-sampled t-tests also illustrated this contrast, where *T. picta* was shown to travel further than *M. rajah* (t = 2.53, df 5, P = 0.052) and *S. muelleri* (t = 2.29, df 8, P = 0.052) before seeking cover. *Tupaia tana* was also shown to travel further than both *M. rajah* and *S. muelleri* (t = 2.53, df 4, P = 0.065 and t = 2.25, df 7, P = 0.059 respectively).

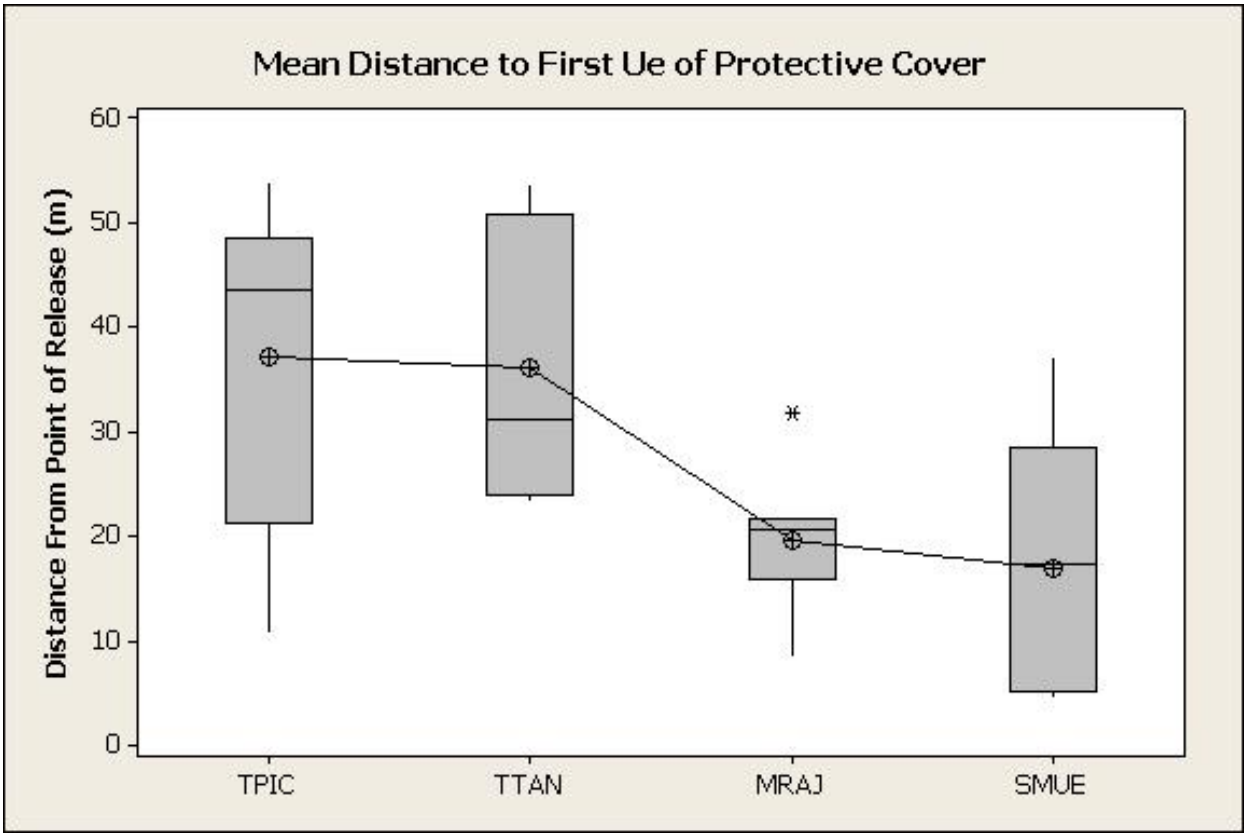


Figure 3.17: Box-plot of four species: Painted treeshrew (*Tupaia picta;* TPIC), large treeshrew (*T. tana;* TTAN), brown spiny rat (*Maxomys rajah;* MRAJ) and Muller's rat (*Sundamys muelleri;* SMUE) showing mean distance to first use of protective cover within the first 100 m following release (ANOVA; $P = 0.012$).

3.4 Discussion

Spool and Line Method: In this study spool-and-line tracking has proven to be a valuable method of recording the fine scale movements of non-volant small mammals in tropical rainforests. From the nylon thread paths, I was able to determine the exact routes of travel to the nearest 10 cm, and was able to gain detailed insight into both the horizontal and vertical space use by different species, use of downed woody debris, and central to this study, their behaviour at habitat edges. With the exception of Shadbolt and Ragai (2010), this is the first study of this nature to be carried out in an industrial timber plantation on Borneo, and focussed on species for which very little in known, even from natural forest habitats.

No animals with the exception of some individuals of *M. rajah* (Figure 3.18) exhibited any noticeable adverse or unusual behaviour related to handling and attachment of the spool and line device (see also Shadbolt and Ragai 2010). Furthermore, regardless of whether movement was influenced by the attachment of the spool or by handling, animals would still need to make conscious decisions about their movement pattern based on the immediately perceivable habitat that they interact with continually.

Figure 3.18: Brown spiny rat *(Maxomys rajah)* attempting to remove spool device soon after attachment. (Photograph A. Shadbolt 2009)

Flight Response: One concern with the spool-and-line method is that the interpretation of movement paths may be confounded by the escape behaviour exhibited by the animal (Shanahan *et al.* 2007) immediately post-release. While neither Shanahan *et al.* (2007) nor Shadbolt and Ragai (2010) recorded any measured flight responses in their study animals, this study illustrated that all species with the exception of *T. tana* showed at least one step length or turning angle correlation with distance from release point in novel patches.

In novel patches, only *T. picta* showed a positive correlation between mean step length on the ground and distance from origin over the entirety of the pooled movement paths, however the opposite was observed for *T. picta* released in home territories where mean step lengths decreased with distance from origin. This is an interesting observation as it may suggest two different patterns of movement relative to the two release scenarios. One explanation may be that in novel patches where animals were unfamiliar with their new environment, the shorter step lengths observed immediately post-release could illustrate a search strategy that increases ability to find resources such as food and/or protective cover, or to evade perceived predators. Conversely in home territories where animals are assumed to be familiar with the physical geography of their habitat, their longer initial step lengths may enable them to reach known cover or food resources more directly and efficiently.

In terms of a measurable flight response to human handling, the movement observed in the novel patches for *T. picta* were counterintuitive to what a flight response might logically represent, where a fleeing animal might be expected to move in long straight movements approaching a ballistic trajectory as it moves away from the point of release. However, it is difficult to determine for this species whether or not these movements constituted flight responses, as one would assume a response to human handling would be the same regardless of release scenario.

In novel patches, mean turning angles of both *T. longipes* and *M. rajah* were negatively correlated with distance from the origin. As with step lengths for *T. picta*, this response again seems counter intuitive to what would normally represent a flight response. Rather than moving off from the point of release on a relatively ballistic alignment, turning angles decreased with distance over the entire lengths of the paths. However it is possible that these flight responses

could represent more tortuous movement resulting from an immediate search for protective cover in contrast to a more directed searching behaviour.

The differences observed between tupaiids and murid rodents in terms of use of protective cover within 100 m of release could be explained by either a) the greater motility of tupaiids (See Emmons 2000) compared with the murid rodents, or b) due to the fact that some murid individuals were released before nightfall and hence required protective cover before commencing normal movement activity (Payne and Francis 2005) after dusk. However this observation is likely to be a combination of the two phenomena rather than either of the two in isolation. The more tortuous paths of murid rodents compared with tupaiids may also illustrate the greater motility of the latter group, and also possibly of different search strategies between groups.

Response to Edge: No animals were released more than 50 m inside the edge of forest patches, and therefore most were likely to have been exposed to a wide range of edge effects (see Laurance *et al.* 2002) throughout the length of their tracked paths. Where forest edges adjoin maturing acacia plantation compartments, many of the edge effects would be expected to be less pronounced than where the forest patch adjoins a road or other open area. At roads it is likely that the absence of vegetation acts as a deterrent to small mammals due to inadequate provision of cover from real or perceived predators (Strevens 2007).

Significance of responses to a range of edge features was statistically tested by Shadbolt and Ragai (2010) using the Exact Binomial Test of Goodness of Fit method for brown spiny rats released in novel patches. Here their null hypothesis was that animals would cross an edge feature at random. However significance tests were not performed in this present study due to the

low sample of independent replicates, where many of the observations were nested within a much smaller number of individuals. However although no significance tests were able to be performed for this aspect this study, some clear patterns emerged that can inform both plantation management and future research needs (refer also Chapter 5).

In this study, individuals of different species were found to react differently to habitat edges. Two species; *T. longipes* and *T. picta* were found to move relatively freely into and out of acacia indicating that acacia edge may not pose a significant barrier to movement, whereas the acacia was found to pose a potential barrier to *M. rajah* (see also Shadbolt and Ragai 2010) and possibly also for *T. tana* pending a larger sample size for this species. However while GP do not list any records of *M. rajah* from acacia forest, five captures of *T. tana* were recorded as being captured in >3 year old acacia between 2005 and 2008, and Wilson *et al.* (2006) also recorded a very old specimen of *T. tana* in 6 – 7 year old acacia forest near Samarakan. This indicates that the acacia matrix may not be as much a barrier to dispersal for *T. tana* as the spool-and-line tracking reported from this study suggests.

Although *M. rajah* and *T. tana* did not cross into the acacia as readily as *T. longipes* and *T. picta*, it may be that their detection and use of corridors could be more efficient than the latter two species on account of being more likely to remain within natural forest. In this sense they may be more likely to be funnelled through a linear natural forest habitat by being repelled away from acacia edges than they are to move out of the natural forest and into the surrounding matrix. Therefore it is important to note that for species like *T. tana* and especially *M. rajah*, corridors may be the primary mechanisms by which they are able to disperse across a landscape to neighbouring patches, particularly during the early stages of the plantation establishment, unlike the more matrix-tolerant species that may be able to disperse through acacia.

However for species like *T. longipes* and *T. picta* that may be less likely to use forest corridors as their primary means of dispersal, it may be misleading to refer to these areas of forest as corridors at all. Dictionary definitions of 'corridor' imply a) some form of movement, and b) a degree of protection afforded to the body which passes along it (Saunders and Hobbs 1991). This study has provided some evidence that these two species may be less likely to use linear forest habitats as movement corridors than would species such as *M. rajah* and *T. tana*. If this is indeed the case, their movement, dispersal ability and survival could rely heavily on the quality of the acacia matrix; a sink habitat that may, if inhospitable, entail a range of threats to their survival.

In this study roads were found to pose likely barriers to dispersal for *T. picta, T. tana* and *M. rajah.* Although the barrier effect of roads was not observed for *T. longipes*, this is likely the result of the low sample size (n = 4 road encounters); at all of which animals moved parallel with roads without crossing. With a larger sample it is possible that roads would represent a barrier for this species too. Therefore as roads were shown to pose a potential barrier to dispersal for all species that encountered them, if these same responses were found to occur across longer temporal scales that were not dictated by a maximum tracking distance of 240.00 m, these linear landscape features are likely to play a significant role in directing animal movement and dispersal similar to that of the acacia matrix discussed above.

Movement orientation data from five *T. picta* released at the T1A forest patch in 2007 also illustrated behaviour that appeared to suggest a negative response to habitat edges; particularly the road feature (Refer Figures 3.4 – 3.10). Here significantly greater proportions of animal movement were directed away from the forest road compared with movement toward it, and pooled data from all five animals resulted in a linear movement trajectory along the general alignment of the patch. As birds of prey are likely to be the main predators of treeshrews

(Emmons 2000), this may explain the reluctance of these species to venture into or across wide, open spaces like forest roads.

Forman *et al.* (2003) identify that road crossing ability in animals is largely a function of an individual's behaviour as well as its habitat requirements. Therefore although most individuals in this study were found not to cross the roads they encountered (33 of 34 encounters did not result in crossing movements) the roads are likely to act as dispersal *filters* as opposed to rigid barriers, where it as assumed that a small percentage of individuals may successfully cross. However, such crossing attempts are likely to place the individual in an increased danger of predation (Forman 2003; Soule and Gilpin 1991).

Old haul trails were not found to pose barriers to dispersal for any species that encountered them. Although not investigated in this study, there is likely to be a gradient in edge response by animals to variable forest road width, with the spectrum ranging from main forest roads such as those considered in this study (Figures 3.19), to regenerating haul trails with medium to dense growth of seedlings and saplings (Figure 3.20). Roads of intermediate width in order of decreasing barrier effect would include 1) secondary roads with low traffic volumes, 2) seldom used roads (Figure 3.21), 3) disused/abandoned roads (Figure 3.22), 4) recently formed mineral-earth haul trails (Figure 3.23), and 5) older haul trails with the mineral earth surface beginning to be covered with accumulated leaf litter (Figure 3.24).

Figure 3.19: Forest road bisecting the Sungai Mina conservation corridor, Planted Forest Zone, Sarawak, East Malaysia (Photograph A. Shadbolt 2006).

Figure 3.20: Old haul trail area regenerating in native saplings, Samarakan, Planted Forest Zone, Sarawak, East Malaysia (Photograph A. Shadbolt, 2010).

Figure 3.21: Typical seldom used forest road, Kalabat, Planted Forest Zone, Sarawak, East Malaysia (Photograph A. Shadbolt 2007)

Figure 3.22: Disused forest road, Tubau, Planted Forest Zone, Sarawak, East Malaysia (Photograph A. Shadbolt, 2007)

Figure 3.23: Recently formed mineral earth haul trail, Kalabat, Planted Forest Zone, Sarawak, East Malaysia (Photograph A. Shadbolt, 2007)

Figure 3.24: Old mineral earth haul trail (right) with early accumulation of leaf litter and some seedling re-growth. Samarakan, Planted Forest Zone, Sarawak, East Malaysia (Photograph A. Shadbolt 2009).

Use of Substrate: In this study all species were found to select logs and downed woody as efficient travel routes where step lengths were found to be longer on these substrates than on the ground. This observation suggests that the use of this form of coarse woody debris may be attributed to a strategy which maximizes travel efficiency. In this sense, logs could be used as navigational cues (Waldien *et al.* 2006), offering fast and direct routes with fewer obstacles than travelling on the ground (Bakker, 2006). McAdam and Kramer (1998) suggest that where small mammals select travel routes on more complex substrates that this requires them to focus on nearby objects, and that in order to scan more distant fields of vision for potential predators, this may require the animal to cease forward movement. In contrast, logs provide a comparatively easy substrate for movement which could allow animals to scan for and detect potential predators while in motion and whilst also providing readily accessible protective cover if required (Waldien *et al.* 2006).

Incidences of non-volant small mammals entering water bodies are seldom reported in the literature. While many murid rodents are known to be very capable swimmers, this is possibly the first record of a tupaiid entering a water body. Despite extensive literature search over the course of this research programme (e.g. Banks 1931; Charles and Ang 2010; Chasen 1940; Darmaraj and Sah 2010; Davis 1962; Emmons 2000; Harrison 1964; Hose 1893; Kawamichi and Kawamichi 1979; Lyon 1913; Payne and Francis 2005; Wells 2005; Wells *et al.* 2004), no accounts of this behaviour have come to light. The only reference relating the treeshrews of genus Tupaia to water were those of Cantor (1846) for the ruddy treeshrew *(T. ferruginea)* in Peninsula Malaysia who wrote: “They are also fond of water, both to drink and to bathe in”. Therefore that two *T. tana* were recorded moving into water at the same release site was therefore an unusual and unexpected finding.

However it is unclear as to what the motivation for entering the water may have been. This was particularly puzzling as both recorded instances entailed moving out from the protective cover of the habitat patch, and into an open wetland area (Figure 3.25) where one would anticipate a heightened risk of predation from avian predators. Further tracking of *T. tana* is therefore recommended in order to a) provide additional evidence of water use by this species, and b) supplement field data related to behaviour at other habitat edges such as roads and acacia for which data were insufficient to perform meaningful statistical analysis.

Figure 3.25: Open wetland area adjacent to the Samarakan release patch where movement paths of two large treeshrews *(Tupaia tana)* entered standing water (centre right). Samarakan, Planted Forest Zone, Sarawak, East Malaysia (Photograph A. Shadbolt 2007).

Conclusions: This study has illustrated the differences in behaviour and response of a range of non-volant small mammals to some of the effects of habitat fragmentation in the PFZ; most significantly the presence of forest roads and the acacia plantation matrix, and the use of downed woody debris for movement and cover. Moreover it has provided evidence that for some species forest roads and acacia compartments may represent significant barriers to animal movement and dispersal, while for other species acacia compartment edges were found to be moved across with relative ease *(i.e. T. longipes* and *T. picta*). From these observations, the knowledge that different species perceive their landscapes very differently from one-another is reinforced. To this end, not all species may recognise and use linear forest habitats as *'corridors'* in the way we imagine them to be used, and similarly may not recognise acacia forest as a *'matrix'* environment that is inhospitable to that species.

Conversely, for species like *T. tana* and especially *M. rajah* for which acacia was seen as a barrier to movement, these species may be more likely to use linear forest landscape units as corridors where any movement would remain constricted within, and funnelled along a linear forest habitat. While this behaviour would improve the way in which corridors are used by these species compared with more matrix tolerant species, where the natal or existing habitat represents an isolated forest patch delimited by roads and acacia plantation rather than a corridor connecting two or more forest habitats, their ability to traverse the matrix could be significantly inhibited. Thus their ability to disperse to a neighbouring patch could be significantly compromised, with adverse implications for effective metapopulation dynamics.

However the persistence of this faunal group may in-part rely on maintaining the current and relatively even distribution of natural forest areas throughout the landscape mosaic, and ensuring that forest patches are located near enough to each other to allow for even a low probability of

dispersal for the most matrix intolerant species. Furthermore, managing the acacia matrix for the retention of downed woody debris may provide an effective strategy to aid animal movement and facilitate predator avoidance, thus improving the fitness of dispersing individuals and limiting their residency time within an environment that may be potentially inhospitable to some species.

CHAPTER 4

Home Range Behaviour and Dispersal Ability of the Painted Treeshrew *(Tupaia picta)* in a Fragmented Plantation Landscape in Sarawak, East Malaysia

Abstract

Painted treeshrew (Tupaia picta) *movement and behavior was recorded by radio telemetry in small patches of remnant hill dipterocarp forest embedded within a fast growing industrial timber plantation matrix in the Planted Forest Zone, Sarawak, East Malaysia. Home range size was found to be larger than those of four Tupaiids in secondary forests in Sabah, while dimension, and average daily movement distances were found to be similar. Animals that were released into small forest remnants outside of their home ranges to measure response to unfamiliar habitats, forest edges and habitat fragmentation during a simulated dispersal event were found to cover long distances within relatively short timeframes, and were found to be able to occupy both secondary forest and established areas of acacia plantation. Painted treeshrews were found to use multiple nest sites which were located predominantly within cavities in hollow logs, root tangles or subterranean burrows. Nest construction was found to be similar to that of other treeshrew species, consisting of a ball of teased wood fibers surrounded by layers of overlapping leaves. From population viability analysis using VORTEX 9.99b software, the viability of semi isolated populations of* T. picta *in remnant forest patches was found to be influenced by patch size, habitat quality and the ability of patches to operate as a semi-connected metapopulation.*

Key Words: *Tupaia picta*, painted treeshrew, *Acacia mangium*, fragmentation, small mammals, Sarawak, Planted Forest Zone, translocation, dispersal.

Title Page Image: Painted treeshrew *(Tupaia picta)* trapped in the Samarakan Conservation Forest, Planted Forest Zone, Bintulu Division, Sarawak, East Malaysia (Photograph A. Shadbolt 2006).

4.1 Introduction

This study uses radio telemetry and camera trapping to record daily movement behavior, home range area and use of nest sites for the painted treeshrew (*Tupaia picta)* residing in secondary forest patches within the Planted Forest Zone (PFZ) of Sarawak, East Malaysia (refer Chapter 1). I also investigate and discuss the impact of habitat fragmentation on the dispersal ability of the painted treeshrew during a simulated a dispersal activity achieved by translocating animals to small isolated patches of secondary forest outside of their assumed home ranges.

Natural habitats are becoming increasingly fragmented by human activity (Davies 1998; Spellerberg and Sawyer 1999; Bakker 2006), and in many places populations exist in isolated or semi isolated habitat fragments (Lande and Barrowclough 1987; Spellerberg and Sawyer 1999; Holland and Bennett 2009) rather than in the continuous habitat that existed prior to fragmentation (E.g. Forman 1995). While the majority of treeshrew-related autecological studies have taken place either in continuous primary or secondary forests, few (e.g. Charles and Ang 2010) have studied treeshrews in fragmented and/or plantation landscapes such as those occurring across the tropics and within the PFZ.

The painted treeshrew *(Tupaia picta;* Thomas 1892*)* is a Bornean endemic confined to an area between Balingian on the Sarawak coast, East Malaysia, and Tasek Merimbun in Brunei Darussalam. Although not occurring in Sabah (Banks 1931; Payne and Francis 2005; Harrison 1964; Chasen 1940), *T. picta* has been described by Harrison (1964) as being very much like the eastern Sabah form of *T. tana* in its appearance. An additional sub species, *T. p. fuscior*, is known from just three locations on the Kalimantan coast, Indonesia, between Samarinda and Labuhan Kelambu (Payne and Francis 2005).

Although *T. picta* is described by Charles and Ang (2010) as species of pristine forest, within the secondary forest/acacia plantation matrix of Sarawak's Planted Forest Zone (PFZ) it remains one of the most common species of non-volant small mammal captured during trapping inventories (See Chapter 2). However despite being so common in the PFZ, and aside from often anecdotal glimpses into the ecology of this species peppered throughout the literature, comparatively little has been published on its ecology and behavior compared with the other Bornean tupaiids covered in the comprehensive study by Emmons (2000), and others by Wells (2005), Wells et al (2004), Wells *et al.* (2006), Clarke *et al.* (2009) and Charles and Ang (2010). As a result, little is known of the ecology of *T. picta* other than it is diurnal (Payne and Francis 2005), that it survives in old growth and secondary forests, and that it shows some adaptability to disturbed habitats as evidenced by its survival in conservation set-asides and forest remnants surrounded by >5 year old tree plantations in the PFZ (Han and Stuebing 2008b).

Conservation set-asides aim to provide connecting corridors and virtual 'lifeboats' for both floral and faunal biodiversity (Stuebing 2005). However while these conservation areas potentially provide benefits for wildlife conservation and management at a landscape scale, much of the PFZ's remaining natural forests remain in a fragmented state across a range of scales as a result of patch isolation within the acacia matrix, or through fragmentation by forest road networks, haul trails, waterways and harvesting operations. While the fragmented forest patches are most likely to lose some species as their increased isolation makes re-colonisation less probable in the long term (Jacquemyn *et al.* 2003), *T. picta* appears to be one species that may be able to persist within such a landscape mosaic (Refer also Chapter 2 and Chapter 3).

Home ranges are dynamic in nature (O'Farrell 1978). Most vertebrate species have a home range comprising an area in which daily movements are made in order to find food and shelter, and some also have smaller territories around dens or nests which are defended against other individuals of the same species (Forman 1995). However in the case of the treeshrew species studied to date, their territories cover the entire home range, with multiple nest sites distributed throughout their home range area (Emmons 2000). Armed with an understanding of home range size for *T. picta*, we can be more confident in predicting patch population size, and estimating the carrying capacity of specific areas of forest under investigation. Furthermore, by knowing the area requirements of *T. picta*, and drawing on known biological and behavioural characteristics of the species and on a range of environmental factors, this allows us to perform more accurate population viability analysis (PVA) which can be extrapolated to the landscape scale.

Another important aspect of small mammal research is the study of nesting behaviour. Nests of Bornean treeshrews have been located and described through spool-and-line tracking (Wells *et al.* 2006) and radio tracking (Emmons 2000b; Wells *et al.* 2006) to reveal nest location, type, architecture and patterns of use between study species. However, to date all published nest site investigations of the Bornean treeshrews have taken place in Sabah, and hence beyond the natural range of *T. picta* (Banks 1931, Chasen 1940, Harrison 1964, Hose 1893, Payne & Francis 2005).

Furthermore, many studies of the ecology of small mammals on Borneo, with few exceptions (e.g. Stuebing and Gasis 1989; Charles and Ang 2009), have worked in primary or secondary forest habitats. Because so much of Borneo's original forestlands are now being rapidly converted to oil palm or fast growing industrial timber plantation estates, an understanding of a species' ecology in these kinds of heavily modified environments may be critical in planning for

its long term population viability. This is especially relevant today given that these areas can be managed for multiple values including biodiversity conservation (Meijaard and Sheil 2008), thus engaging 'industry' in complementing conservation efforts in Sarawak's Totally Protected Area (TPA) network; a network that will eventually amount to 10% of the State's forested land area (Hazebroek and Morshidi 2001; Stuebing 2005).

Small mammal inventories carried out in the PFZ reveal that many species are able to utilize remnant dipterocarp forest patches, corridors, and also acacia plantation compartments. Furthermore Ragai and Tuen (2007) show that plantation compartments nearing the end of their rotation (± seven years) actually supported a higher species richness of small mammals than did the immediately adjacent secondary forest, illustrating that if managed well, heavily managed plantation landscapes can have the potential to provide conservation value (McShea *et al.* 2009). However, whether species currently occupying the PFZ are purely transitory or whether they are permanent components of the new ecosystem may largely be reliant on management actions that provide the diversity of resources, such as coarse woody debris (see Shadbolt and Ragai 2009) and nest sites. The latter may be particularly important given that almost all small mammals need nests as shelter, sleeping sites or for rearing young (Wells *et al.* 2006).

Attempting to locate sleeping sites of small mammals by active searching is almost impossible (Moraes Jr. and Chiarello 2005). This study therefore also uses radio telemetry and camera trapping to investigate the location, construction and use of nests of *T. picta* in secondary forest remnants embedded within acacia plantation compartments of the PFZ, and compares them to those of other Tupaiids studied by Emmons (2000a; 2000b) and Wells *et al.* (2006) in Sabah. This paper also discusses possible nest site sharing between *T. picta* and the tree-striped ground

squirrel *(Lariscus insignis)*, fuelling the as-yet unanswered question (Emmons 2000a) of *'who builds the nests?'*

This study therefore complements the spool and line study reported in Chapter 3 for this species to investigate these phenomena across different spatial and temporal scales. Findings from this study are compared and contrasted with the data published by Emmons (2000) for species studied in Sabah, thus supplementing the slowly coalescing body of knowledge of these forest dependent animals. A simple PVA using the software package Vortex 9.99b (Lacy 1993) is also performed to predict probability of long-term population survival for the species in the areas of forest studied.

The use of radio transmitters on painted treeshrews in this study also represents the first known radio telemetry study of any wildlife species to be carried out in the State of Sarawak. Ultimately it is hoped that this paper will not only contribute to the pool of knowledge on this little-studied species, but also be of practical use in illustrating to forest managers some of the key habitat requirements that go towards ensuring the long term viability of such seemingly common species. This information is critical if appropriate management interventions are to be applied in a timely manner, rather than relying on reactive species recovery strategies after once abundant local populations have declined to vulnerable levels.

4.2 Methods

Study Sites: Investigations into home range and use of nest sites was carried out at two sites in the PFZ, Bintulu Division, Sarawak, East Malaysia; The Samarakan Conservation Forest (SCF) (N 02°56.462' E113°07.603') (Figure 2.6) and the Kakus Nursery Forest (KNF) (N 02°46'14.89" E113°13'28.24") (Figure 2.2). The SCF is composed of secondary dipterocarp forest, surrounded by, and in some areas mixed with, ±9 year old acacia. The forest is characterized by a dense canopy at a height of ±25m and a relatively sparse understorey compared with the areas of acacia. The acacia areas are characterized by a canopy height of ±15 m, a dense under storey consisting of wild gingers (Zingiberaceae family), rattans (*Calamus* sp), grasses, ferns, and large tree-fall gaps that supported regenerating dipterocarps, figs and other secondary growth trees (Ragai and Tuen 2007). Fieldwork was carried out at the SCF site between 26th October and 13th November 2008 and for a short session in March 2009, and at KNF between 25th July and 21st August 2009.

Fieldwork was carried out at two separate sites within KNF; Kakus East (N 02°45'58.30" E113°13'32.40") and Kakus West (N 02°46'35.70" E113°13'07.80"). Kakus East (c.139.00 ha) was separated from Kakus West (c.36.00 ha) by a wide but seldom used forest road that was assumed to pose a potential barrier to dispersal for *T. picta* (Refer Chapter 3). Both sites were separated from the adjacent acacia plantation compartments by forest roads, and unlike SCF neither included areas of acacia mixed within the forest patch.

Vegetation at the two sites within KNF was more variable than that of SCF, and was composed a mosaic of different vegetation types. Some areas consisted of secondary forest similar to that of SCF with a high (±25m) canopy, while other parts of the forest were dominated by dense, even

aged sapling re-growth where areas were recovering from shifting cultivation (temuda) with a canopy height of less than 10m. These areas were also interspersed with large patches of dense fern with little-to-no tree canopy cover where the abandonment of the cultivation cycle of temuda had been more recent. The KNF was also different to SCF in that it was characterised by old logging haul roads throughout.

The translocation study was carried out only at the Samarakan study site, between 26th October and 13th November 2008, and again for a short session in March 2009. The release site (N 02°54′56.51″, E 113°06′18.10″) in plantation compartment T1A near the SCF was the same release site used for the spool and line tracking discussed in Chapter 3.

Trapping & Animal Handling: Trapping methodology is discussed in detail in Chapter 2. Upon capture, animals were identified using Payne and Francis (2005) and were transferred from the wire cage traps to cloth bags by gently tapping on the end of the cage and allowing them to fall into the opened end of the bag. To control for handling bias, all animals were transported back to field bases by vehicle, held in the cloth bags in a cool dark room until transmitters were fitted (see below), before being transported to release sites for release the same day.

Sirtrack™ single-stage transmitters (Figure 4.1) with a pulse rate of 40PPM, weighing ±5.5g each and tuned to frequencies from 162.100MHZ to 162.280 MhZ were used. Transmitters had an expected battery life of seven to eight months. Transmitters were attached to the animals by restraining them inside the cloth bags with just their head and neck areas free. Replaceable cable-tie collars were tightened with pliers to a secure fit so the unit was not able to pull off over the animals head, but also was not considered so tight as to impede breathing and swallowing of food items. As animals were not anaesthetized during handling, the radio collars were fitted

within the confines of a small room at a field base in order that animals could be easily re-captured should they manage to escape. Each animal was uniquely marked with a small patch of yellow enamel paint on its fur and released in the mid afternoon on the same day of capture by leaving the animal in a half open cloth bag while field personnel retreated quietly from the area. All research on live animals followed American Society of Mammalogists (ASM) guidelines (Gannon *et al.* 2007) and was approved by the University of Canterbury Animal Ethics Committee.

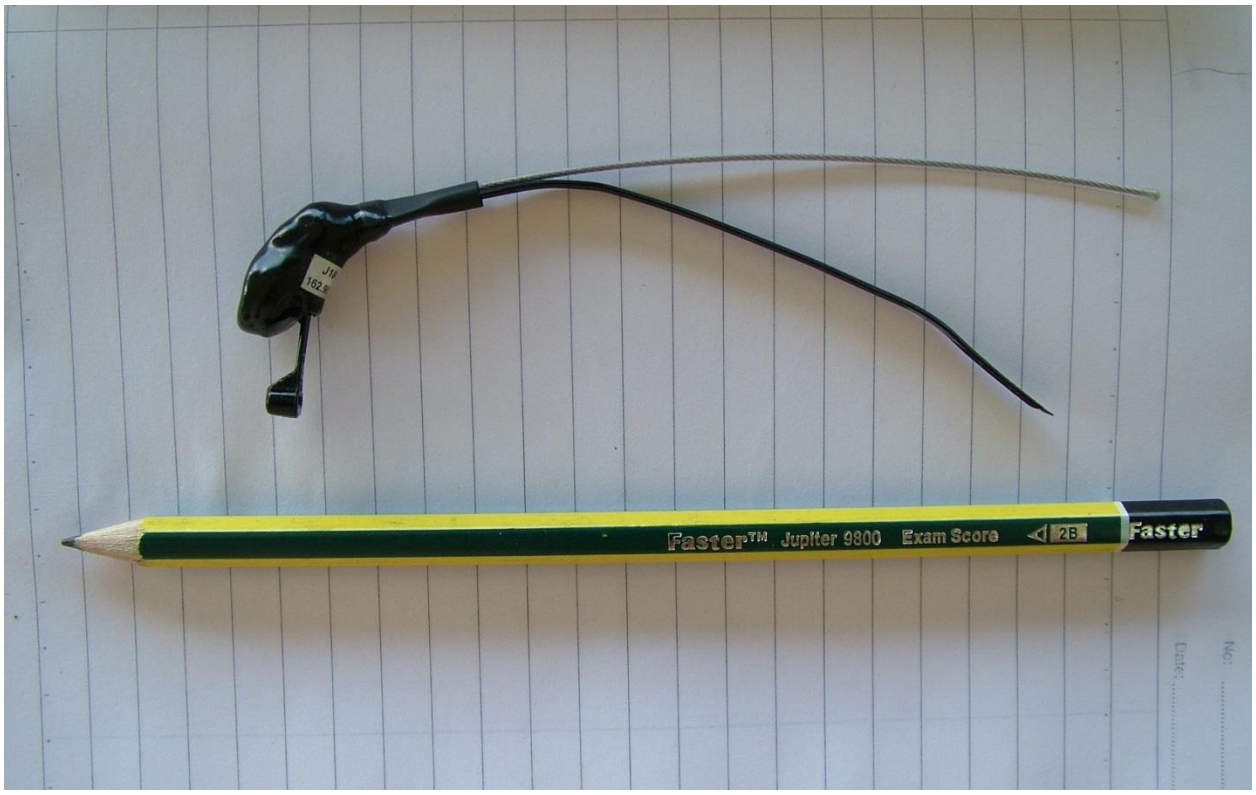


Figure 4.19: Sirtrack™ single stage transmitter weighing ±5.5 g used for tracking painted treeshrews *(Tupaia picta)* (Photograph A. Shadbolt 2008).

Radio Tracking: Animal locations were determined during daytime from intersects of three compass bearings taken from known global positioning system (GPS) points within quick (<10 minute) succession using a Telonics™ TR-4 receiver and a three-element Yagi antenna (Wildlife

Materials Inc., Illinois, USA). At night, after the animal had retired after the day's activity, the general location of individual sleeping sites were determined by homing in on the signal using the TR-4 and Yagi antenna. At the SCF site, due to time constraints associated with concurrent fieldwork, animal locations were recorded just once or twice per day over the study period for that site. However at the KNF site, animal locations were recorded at twenty minute intervals from the time the animal left the nest site until the time it retired for the day over at least three consecutive days, as per Emmons (2000).

After dark, the general location of individual sleeping site was determined by homing in on the signal using the TR-4 and Yagi antenna. Pinpointing the exact location of the nest containing the animal was achieved by detaching the antenna and carrying out fine-scale, close-proximity scanning using just the TR-4 and head-set. The times when animals left their nests in the mornings and entered nests again in the afternoon were signaled by distinct changes in signal strength, and on two occasions by directly sighting animals leaving nests.

Camera Trapping: Camera traps were used to determine frequency of use of individual nest sites, and to record times of arrival and departure from nests. Deercam™ digital camera traps were set up towards the end of the telemetry studies at two nest sites of TPIC4/08 in SCF, and at four nest sites for TPIC1/09 and three nests for TPIC2/09 at KNF.

Cameras were lashed to saplings at approximately the same height as the nest/den, and at distances of approximately three-to-four meters from the target to ensure that the movement/heat signature of such a small animal would trigger the camera trap. Cameras were programmed to take full colour photographs by day, and use an infrared flash at night and/or during low light

conditions. With each trigger just one photograph was taken, and after each photograph the camera would shut down for one minute before re-arming itself.

Population Viability Analysis: The population viability analysis (PVA) computer simulation package VORTEX version 9.99b (Miller and Lacy 2003) was used to model deterministic forces as well as demographic, environmental and genetic stochastic events on populations of *T. picta* in the SCF, and at the two KNF patches. VORTEX software is one of the most popular PVA software packages used in conservation planning (Brito and de Souza Lima Figueiredo 2003).

At the SCF site, the PVA was performed for the entire area of the forest (c.77.50 ha), however at the KNF site PVA was performed for three scenarios: 1) PVA for each of the two patches (36 ha and 175 ha) separated by a forest road, 2) PVA for the entire KNF patch (c.175.00 ha) ignoring the presence of the road as a barrier to dispersal, and 3) PVA simulating metapopulation dynamics between the two discrete patches separated by the road. Thus with the exception of 'scenario three' at the KNF, the other populations were treated as closed populations in the absence of estimated immigration rates from the matrix. Results for these closed scenarios are therefore likely to represent worst-case scenarios for population viability.

For both the SCF and KNF sites, simulations were carried out for both the current state of the forests, and assuming a 2.5% increase in carrying capacity (K) per annum over a period of 25 years in response to natural forest regeneration and improved habitat quality following the cessation of timber extraction, shifting cultivation practices, gathering of non-timber forest products and also reductions in a range of other human associated disturbances.

For each of the scenarios, 1000 iterations were run with initial population sizes deemed to be equal to K for the respective forest patches. Carrying capacity was determined by dividing patch

area by the mean *T. picta* home ranges determined from radio tracking, and multiplying by two in order to account for monogamous pairs sharing the same geographic areas, and also based on evidence of Emmons (2005) that treeshrew home ranges did not generally overlap with neighbouring conspecific pairs. Populations were deemed to be extinct when only one sex remained, and scenarios were modelled for a period of 100 years. Demographic viability was considered to occur when a populations probability of success was greater than $P = 0.9000$ ($P = < 0.1000$ probability of extinction) during the 100 year timeframe (Brito and de Souza Lima Figueiredo 2003).

Population Viability Analysis input variables used in the VORTEX simulations are listed in Table 4.1. In the absence of life history data on *T. picta,* demographic parameters used are largely based on Emmons (2000) experience with other tupaiids from Sabah. Other variables are based on the authors' field records and peer reviewed assumptions on how the species is likely to behave in a fragmented landscape such as the PFZ.

In terms of the initial carrying capacity for a forest patch, this has been based on the results of the home territory radio telemetry study reported in this chapter. The initial carrying capacity is therefore the size of the forest patch divided by the mean recorded home range for that patch, and multiplied by two to account for long-term monogamous pairs (Emmons 2000) sharing roughly the same defendable territory. VORTEX also calculates the mean population size expected at the end of the 100 year model. From this calculation, and taking into account the 2.5% per-annum increase carrying capacity, it is possible to predict the expected mean home range size in hectares at the end of 100 years. It is thus anticipated that mean home range size for each patch should decrease as habitat quality improves.

Table 4.1: Summary of biological and ecological attributes of painted treeshrew *(Tupaia picta)* used as input variables in the computer simulation package VORTEX 9.99b (Miller and Lacy 2003).

Parameter	Value	Source
Definition of Extinction	Only One Sex Remains	Miller and Lacy 2003
Inbreeding Depression Lethal Equivalents	3.14	Miller and Lacy 2003
Breeding System	Monogamous	Emmons 2000
Adult Sex Ratio	1:1	Emmons 2000
% Males in Breeding Pool	100%	
Age of Producing First Offspring M/F (months)	12/12 months	Emmons 2000
Maximum Age of Reproduction	7 years	
Maximum Number of Broods/Year	6	Emmons 2000
0, 1, 2, 3, 4, 5, 6 Broods/Year	5%, 5%, 10%, 15%, 50%, 10%, 5%	Emmons 2000
Maximum Progeny/Brood	2	Emmons 2000
1 Offspring/2 Offspring	5%/95%	Emmons 2000
Sex ratio at birth	50/50	Emmons 2000
Distribution of Number of Offspring	Normal Distribution	
Mortality 0-1, 1-2, 2- Years (M & F)	25%, 10%, 5%	
Initial Population Size	100% Carrying Capacity	
Initial Carrying Capacity (SCF, KNF east, KNF west)	17, 30, 8	Refer Results Section
Future Change in Carrying Capacity	2.5% over 25 Years	
Initial Home Range	9.11 ha	Refer Results Section
Age Range of Dispersers	1 – 5 Years	
% Survival of Dispersers	50%	
Probability of Dispersal From Source	10%	
Catastrophe 1 (Fire) 20 Years	50% Reproduction & Survival	
Catastrophe 2 (Drought) 20 Years	75% Reproduction & Survival	
Harvest	NA	
Supplementation	NA	

4.3 Results

4.3.1 Animals Released in Home Territories

Radio Tracking: Six *T. picta* (three male and three female) were trapped, fitted with transmitters and released again at their respective points of capture (Table 4.2). One male (TPIC4/08) and two females (TPIC3/08 & TPIC6/08) were released in the SCF forest patch, and two male (TPIC2/09 & TPIC3/09) and one female (TPIC1/09) were released the KNF forest patch.

Twenty-three and 16 locations were recorded for TPIC4/08 and TPIC6/08 respectively (Table 7.2). Just six locations were recorded for TPIC3/08 before its radio collar was retrieved at the entrance to a nest. The total range for TPIC3/08 using a convex polygon estimate was 0.2 ha, however as this is a known underestimate of the area actually used by the animal, data for TPIC3/08 are not used in any analysis or further discussion.

Sixteen locations were recorded for TPIC6/08 during the initial 14 day tracking period including five separate sleeping sites. The signal for TPIC6/08 was not able to be received on several days during this tracking period when it was assumed to have strayed beyond the range of the receiver. By March 2009 the signal from TPIC6/08's transmitter could no longer be detected, and therefore any data related to home range is likely to be a minimum estimate of actual area used and is therefore not used in the following analysis.

Table 4.2: Home range and use of space by six painted treeshrews *(Tupaia picta)* fitted with radio collars in habitat patches in the Planted Forest Zone, Sarawak, East Malaysia. **D max** = maximum diameter of home range; **D min** = minimum diameter of home range; **Mean Dist'/Day** = mean recorded distance travelled per day; **Maximum Dist'/Day** = maximum recorded distance travelled in one day; **Area/Day** = mean total area covered within one day; **Total Area Convex Polygon** = total area covered over duration of tracking period using the convex polygon method; **Total Area Minimum Polygon** = total area covered over duration of tracking period using the minimum polygon method; **No. of Points** = Total number of positions located for animals across the tracking period. Means exclude values for TPIC6/08 and TPIC3/08.

Animal	D max (m)	D min (m)	Mean Dist'/Day (m)	Maximum Dist'/Day (m)	Area/ Day (ha)	Total Area Convex Polygon (ha)	No. of Points
Samarakan Conservation Forest							
TPIC3/08 (Female)	90	28	-	-	-	0.20	6
TPIC4/08 (Male)	627	128	-	-	-	9.77	23
TPIC6/08 (Female)	165	91	-	-	-	1.42	16
Kakus Nursery Forest							
TPIC1/09 (Female)	291	287	963(3)	1110	2.19(3)	7.30	103
TPIC2/09 (Male)	390	386	1450(3)	1878	4.39(3)	11.70	107
TPIC3/09 (Male)	283	278	1138(3)	1317	2.88(1)	7.65	76
Mean*	**398**	**270**	**1184**	**1435**	**3.15**	**9.11**	**N/A**

Nineteen locations, including five sleeping sites for TPIC4/08 were recorded over the initial 14 day period, and despite a weak transmitter signal during March 2009, a further four locations were recorded including two new sleeping sites. The 23 locations recorded for TPIC4/08 gave a home range area of 9.77 ha using the minimum convex polygon method. The home range area recorded was oblong in shape, and used the forest edge where it adjoined the Samarakan Nursery complex as the edge of its range. The minimum and maximum diameters of home range for this animal were 128 m and 627 m respectively (Table 4.2), and the range area was not observed to overlap with the recorded areas used by either TPIC3/08 or TPIC6/08 despite their relative adjacency (Figure 4.2). However due to the limited nature of the data, range-overlap cannot be ruled out.

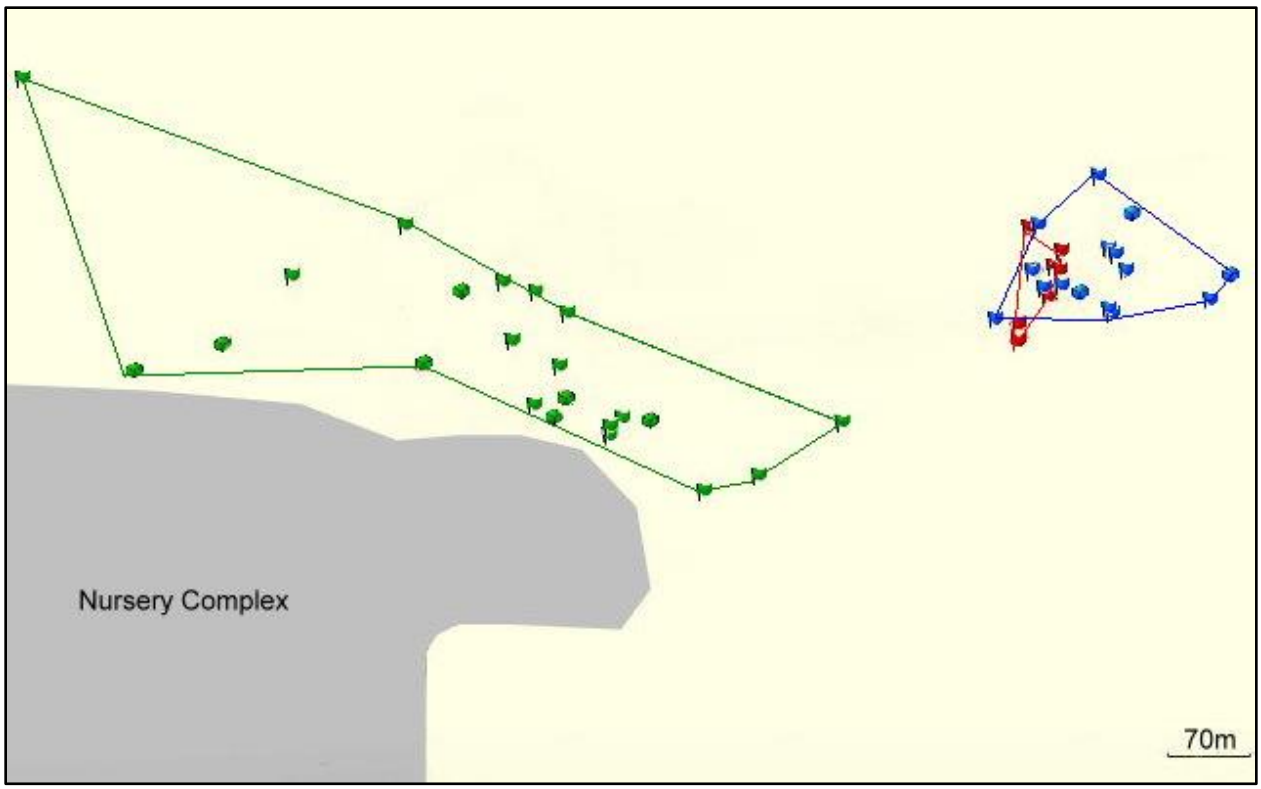


Figure 4.2: Recorded locations for Painted treeshrews *(Tupaia picta)* released in the Samarakan Nursery Forest, 2008. Red = TPIC3/08; Green = TPIC4/08; Blue = TPIC6/08; (Coloured boxes represent locations of sleeping sites).

At the KNF study area (Figure 4.3), one male (TPIC1/09) and one female *T. picta* (TPIC2/09) were trapped in Grid One, and one male *T. picta* (TPIC3/09) was trapped in Grid Two over seven trap nights each. All three animals caught at the KNF site were fitted with transmitters and released. The two animals captured in Grid One were assumed to be a pair, as they were trapped on the same transect just 30 m apart on consecutive days. TPIC2/09 managed to escape free from her radio collar while within the cloth bag and was released before field personnel realized. However the marked animal was re-captured four days later in the same trap that had caught TPIC1/09, and was again fitted with a radio collar and successfully released. One-hundred and three locations were recorded for TPIC1/09; 107 for TPIC2/09 and 76 for TPIC3/09, including five, four and one separate sleeping site respectively.

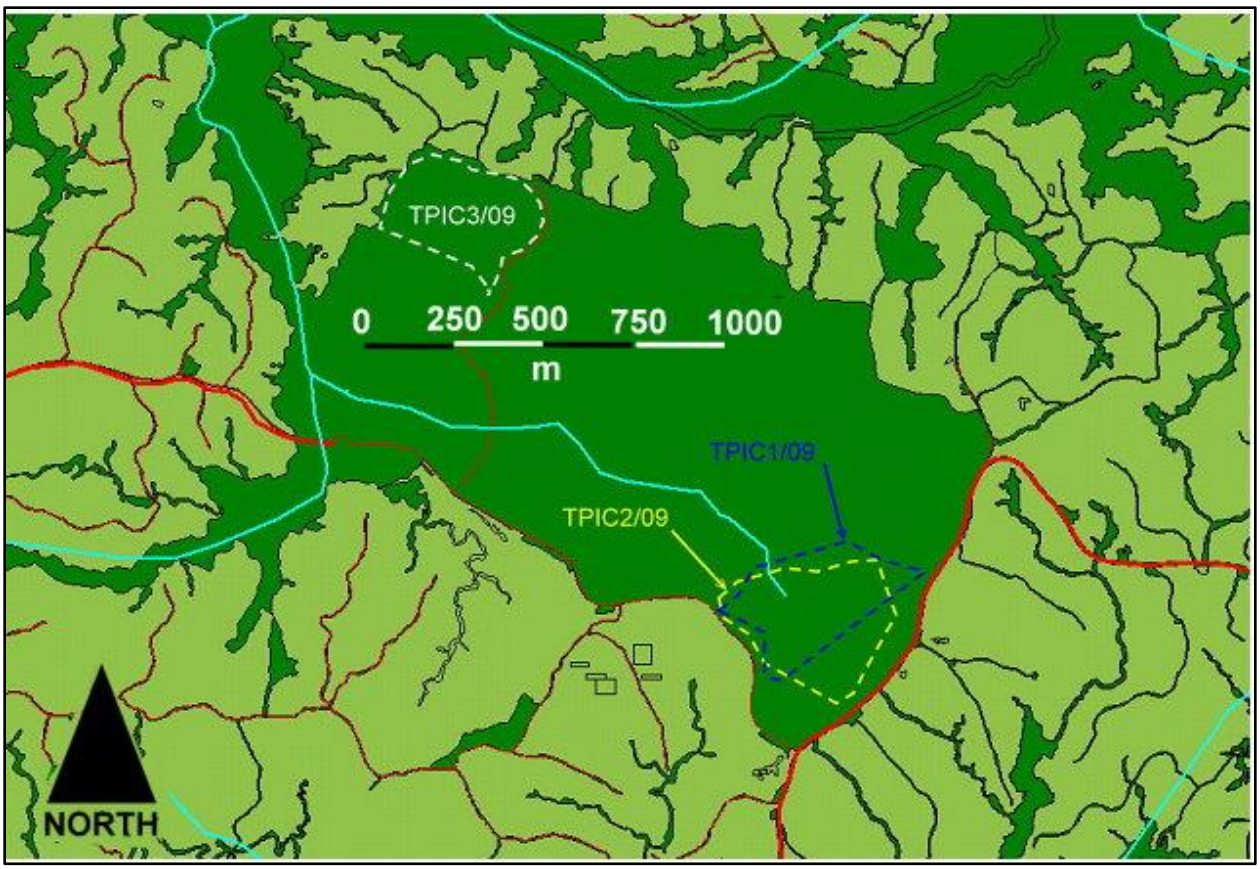


Figure 4.3: Map of the Kakus Nursery Forest study area (large dark green patch) showing location of acacia *(Acacia mangium)* plantation compartments (light green), forest roads (red), streams (blue) and the approximate locations of three painted treeshrew *(Tupaia picta)* home ranges: TPIC1/09 (F), TPIC2/09 (M), and TPIC3/09 (M).

Female TPIC1/09 and male TPIC2/09 shared a similar geographic area for the duration of the tracking, further suggesting that these two animals were a monogamous pair (See Figures 4.3, 4.4 and 4.5). All locations recorded for these animals were within the bounds of the forest road network, with no locations being recorded on the opposite sides of the roads.

Home ranges for TPIC1/09 and TPIC2/09 were 7.30 ha and 11.70 ha respectively, and unlike TPIC4/08 (SCF), minimum and maximum home range diameters were found to be relatively equal with minimum dimensions being just four meters less than maximum dimensions for each (Refer Table 4.2). The mean daily area used by the female TPIC1/09 (2.19 ha) was less than half that recorded being used by the male TPIC2/09 (4.39 ha) (Figures 4.4 & 4.5 respectively).

These differences were also reflected in the mean distances travelled per day of 963 m and 1450 m respectively for female and male. The daily movement behavior of female TPIC1/08 tended to favour the use of tight clusters, as illustrated in Figure 4.4. Here the female spent large parts of the day in relatively small geographic areas compared to the wider ranging behavior of the male, TPIC2/08 (Figure 4.5).

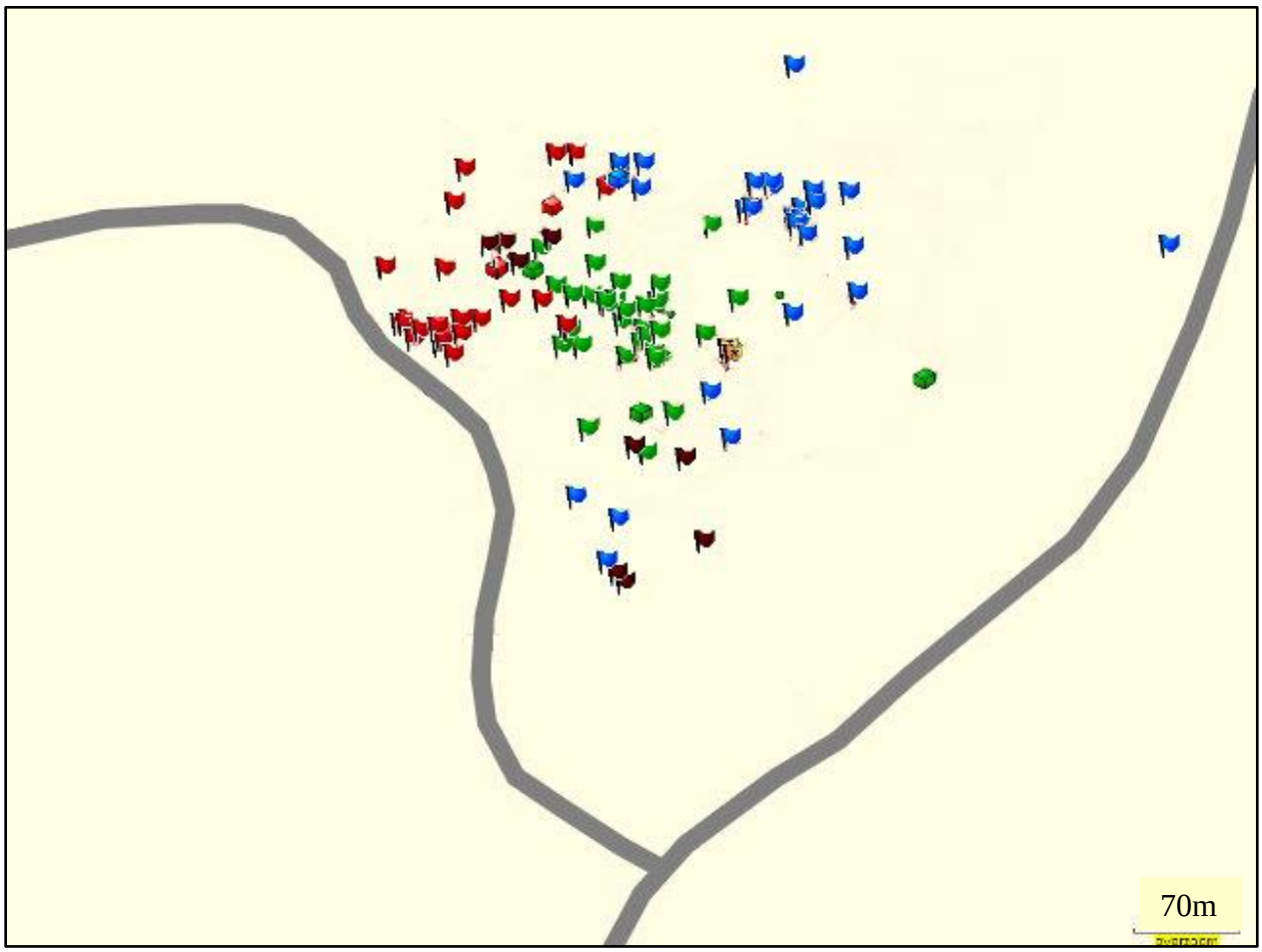


Figure 4.4: Recorded locations for Painted treeshrew *(Tupaia picta)* TPIC1/09 (Female) in the Kakus Nursery Forest (East). Green = 03/08/09; Red = 04/08/09; Deep Red = 05/08/09; Gold = 06/08/09; Blue = 07/08/09 (Coloured boxes represent locations of sleeping sites).

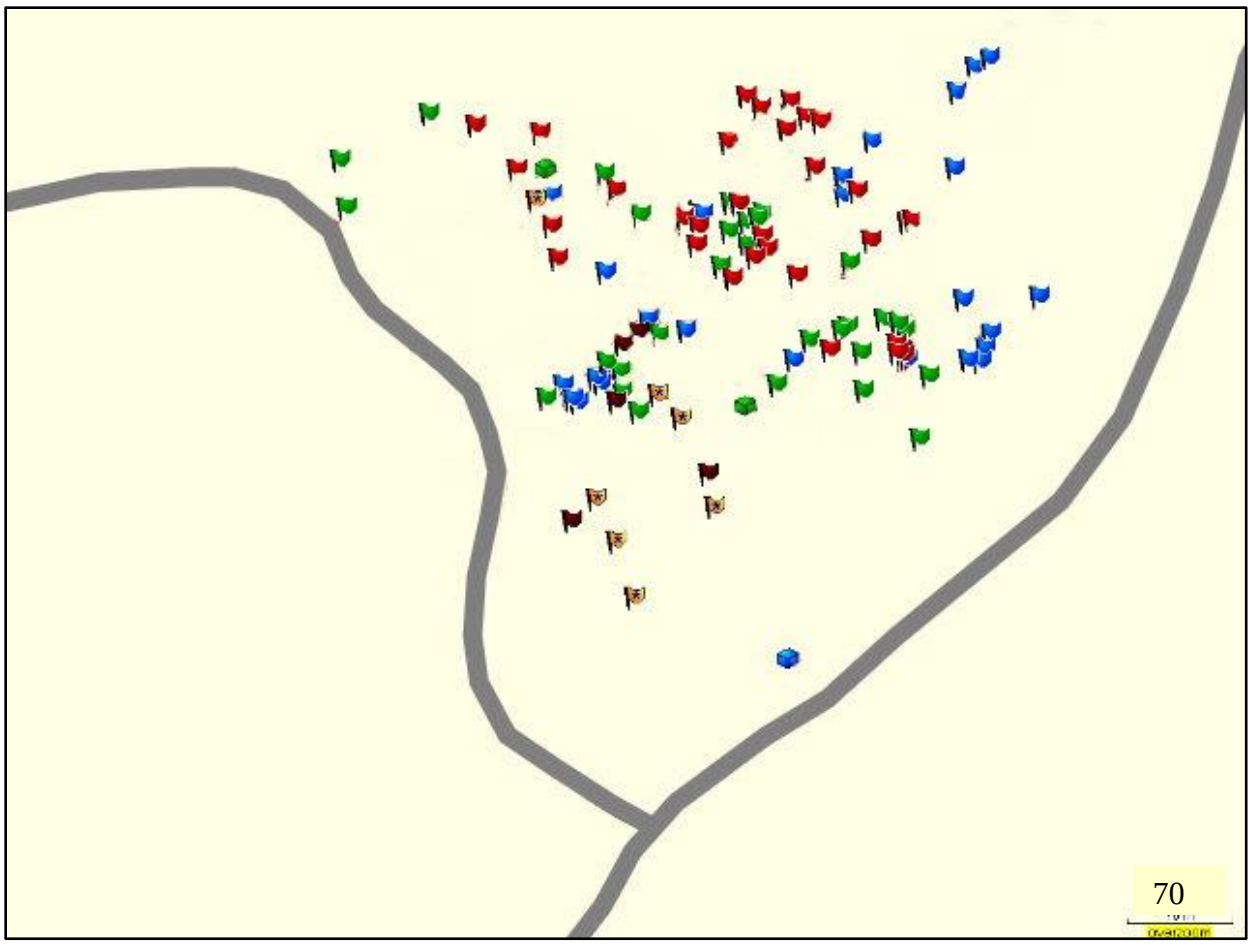


Figure 4.5: Recorded locations for Painted treeshrew *(Tupaia picta)* TPIC2/09 (Male) in the Kakus Nursery Forest (East). Green = 01/08/09; Red = 02/08/09; Deep Red = 0308/09; Yellow = 05/08/09; Blue = 13/08/09. (Coloured boxes represent locations of sleeping sites).

Animal TPIC3/09 used an area of 7.65 ha during the course of the tracking. As with TPIC1/09 and TPIC2/09, home range maximum and minimum dimensions for TPIC3/09 were relatively equal, with just five meter's variation. The Mean daily area used by TPIC3/09 was 2.88 ha, and mean distance travelled was 1138 m and tended to show a clustering of activity. The range area for this individual was apparently influenced by the location of a disused forest road, where the road formed a distinct 525 m long eastern boundary to the animal's home range. No locations were recorded on the eastern side of the road (Figure 4.6).

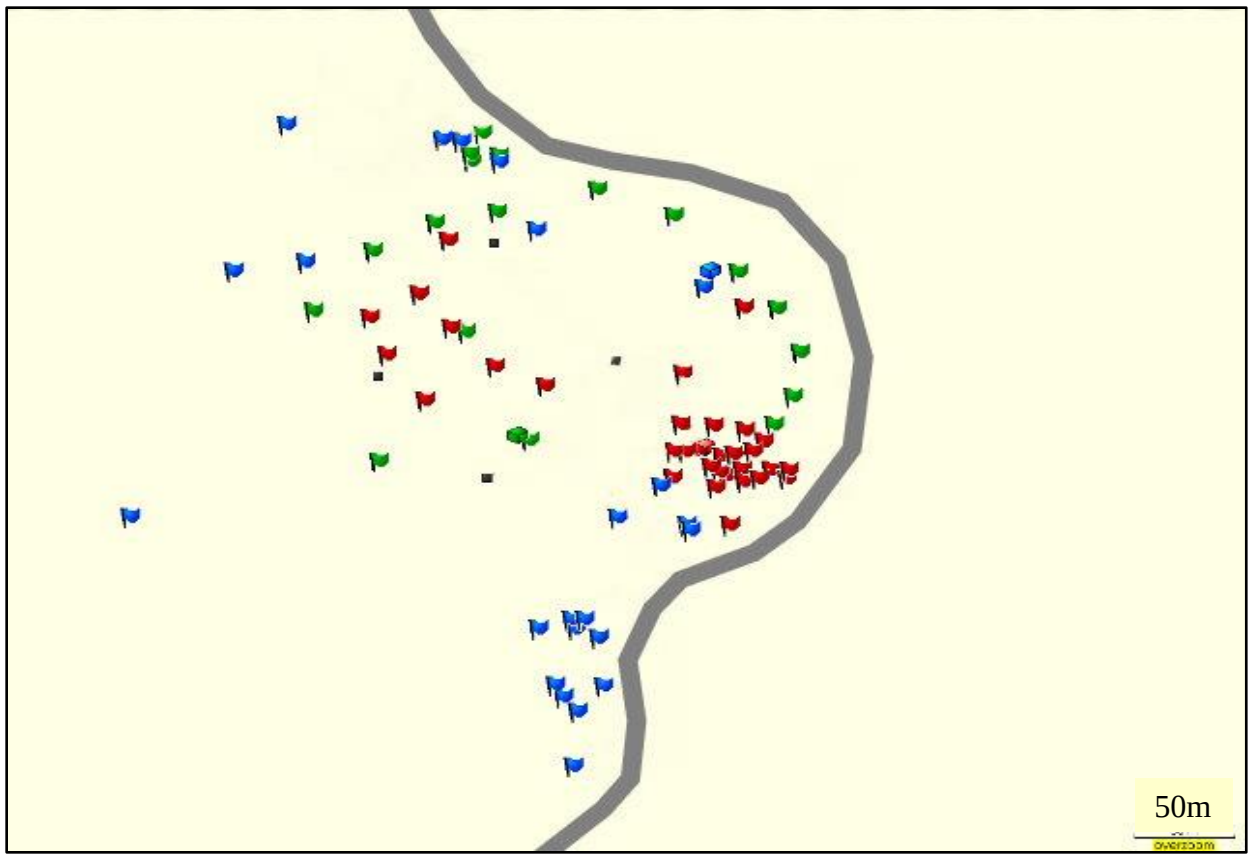


Figure 4.6: Recorded locations for Painted treeshrew *(Tupaia picta)* TPIC3/09 (Male) in the Kakus Nursery Forest (West). Green = 15/08/09; Red = 16/08/09, Blue = 17/08/09. (Coloured boxes represent locations of sleeping sites).

Population Viability Analysis (Refer Table 4.3): At c.135 ha it was calculated that Kakus East would be capable of supporting 15 monogamous pairs (30 individuals), excluding juveniles at the beginning of the 100 year simulation. In 1000 simulations of this population with no future increase in carrying capacity, the population had a probability extinction of $P = 0.530$. Factoring in a 2.50% increase in habitat quality and carrying capacity per annum over a period of 25 years, the probability of population extinction for the patch decreased to $P = 0.027$, indicating a significant probability of long term persistence of *T. picta* within the patch. Accounting for immigration of individuals from the matrix during plantation harvest decreased the probability of extinction even further to $P = <0.000$ (Table 4.3).

Table 4.3: Results of Population Viability Analysis (PVA) using VORTEX 9.99b (Miller and Lacy 2003) for the painted treeshrew *(Tupaia picta)* in three forest patches in the Planted Forest Zone (PFZ), Sarawak, East Malaysia. (K = 2.5% increase in carrying capacity per-annum over 25 years; I = immigration of [n] individuals from the matrix at seven year intervals during plantation harvest).

Scenario	Patch Area	Founder Population (N)	Mean Population Size at Year 100	Probability Extinction (P)	Maximum Available Mean Home Range at 100 Years
Kakus East	135.00 ha	30	21	*P* = 0.530	12.90 ha
Kakus East (K)	135.00 ha	30	44	***P* = 0.027**	6.10 ha
Kakus East (K & I[6])	135.00 ha	30	47	***P* = 0.000**	5.70 ha
Kakus West	38.70 ha	8	0	*P* = 1.000	N/A
Kakus West (K)	38.70 ha	8	0	*P* = 1.000	N/A
Kakus West (K & I[4])	38.70 ha	8	7	*P* = 0.997	11.10 ha
Kakus East (Metapopulation)	135.00 ha	30	15	***P* = 0.081**	18.00 ha
Kakus East (Metapopulation) (K)	135.00 ha	30	38	***P* = 0.066**	7.10 ha
Kakus East (Metapopulation) (K & I[6])	135.00 ha	30	44	***P* = 0.000**	6.10 ha
Kakus West (Metapopulation)	38.70 ha	8	5	*P* = 0.867	15.50 ha
Kakus West (Metapopulation) (K)	38.70 ha	8	11	***P* = 0.079**	7.00 ha
Kakus West (Metapopulation) (K & I[4])	38.70 ha	8	12	***P* = 0.006**	6.50 ha
Kakus Metapopulation	173.70 ha	38	18	*P* = 0.800	19.30 ha
Kakus Metapopulation (K)	173.70 ha	38	49	***P* = 0.060**	7.10 ha
Kakus Metapopulation (K & I[10])	173.70 ha	38	57	***P* = 0.000**	6.10 ha
Kakus Pooled	173.70 ha	38	31	***P* - 0.075**	11.20 ha
Kakus Pooled (K)	173.70 ha	38	59	***P* = 0.000**	5.90 ha
Kakus Pooled (K & I[10])	173.70 ha	38	60	***P* = 0.000**	5.80 ha
Samarakan	77.50 ha	17	0	*P* = 1.000	N/A
Samarakan (K)	77.50 ha	17	18	*P* = 0.905	8.60
Samarakan (K & I[6])	77.50 ha	**17**	**23**	**P = 0.485**	

The c.36 ha Kakus West patch was assumed to be capable of supporting a population of eight animals consisting of four monogamous pairs. Neither simulation, with or without an increase in K over the 25 year period, nor with immigration from the matrix resulted in the long-term survival of the population.

Were both Kakus forest patches able to operate as a single contiguous population, the probability of population extinction was low for all modelled scenarios. However simulation of the two patches as a metapopulation where dispersal from the adjacent patch supplemented the neighbouring population resulted in high probabilities of population extinctions where no increase in K was included in the model. Where increases in K and immigration where included in the model, each patch and the wider metapopulation had low probabilities of extinction.

At SCF, simulations were based on the forest area having a carrying capacity of 17 animals consisting of 8.50 monogamous pairs. Without an increase in K, the probability of population extinction in the forest patch was $P = 1.0000$, and neither an increase in K nor factoring in immigration resulted significant probabilities of survival.

Nest Sites: During the initial 14 day tracking period at SCF, five separate sleeping sites were recorded for TPIC4/08, and 6 were recorded for TPIC6/08. By March 2008 the signal from TPIC6/08's transmitter could no longer be detected, and that of TPIC4/08 was only detected intermittently. However despite the weak signal of TPIC4/08, during March a further three locations were recorded including two new sleeping sites. All locations including nest sites for TPIC4/08 were located within the secondary dipterocarp forest component of SCF, while all those of TPIC6/08 were located in acacia forest. At the KNF sites, five sleeping sites were

recorded for TPIC1/09, four for TPIC2/09 and just one for TPIC3/09 between the 1st and 17th August 2009.

From the 24 nest sites located, animals were found to use a variety of nest locations (Table 4.4). Locations included subterranean burrows (n=6), cavities amongst exposed root tangles, pneumatophore roots or epicormic shoots at the bases of trees (n=4), hollow logs or tree stumps (n=12), above ground tree cavities (n=1) and exposed nests amongst understorey vegetation (n=1). Of the sleeping sites recorded for TPIC4/08, only one site was observed to be used on two occasions, and these occurred on two consecutive nights. For TPIC6/08 two sleeping sites were observed to be used twice during the 14 days; one on two consecutive nights, and another used on two separate occasions but five nights apart. TPIC1/09, TPIC2/09 and TPIC3/09 were never recorded using the same nest site on more than one occasion, however weather conditions prevented nest location on a number of evenings during the study periods where some nests may have been re-visited.

Table 4.4: Types of nests located for painted treeshrews *(Tupaia picta)* released in The Samarakan Conservation Forest and Kakus Nursery Forest.

Animal	Below Ground	Tree Base Cavity	Hollow Log/Stump	Live Tree Cavity	Exposed	TOTAL
The Samarakan Conservation Forest						
TPIC3/08 (Female)	1+					1
TPIC4/08 (Male)	2	1	3	1		7
TPIC6/08(Female)	1+	1+	3+		1+	6
Kakus Nursery Forest						
TPIC1/09 (Female)	1	2	2			5
TPIC2/09 (Male)	1		3			4
TPIC3/09 (Male)			1			1
TOTAL	**6**	**4**	**12**	**1**	**1**	**24**

+ **Nests located in *Acacia mangium* forest**

Twelve nests that were investigated in closer detail to record construction material and design, and all were of similar construction. All nests with the exception of those in hollow logs (see below) consisted of a ball of teased fibers with an outside covering of overlapping layered leaves of varying thicknesses depending on the location of the nest. The single 'exposed' nest (TPIC6/08) was located within mature acacia plantation (Table 4.4), ±450mm above the ground amongst wild ginger and had a thick (±15mm) covering of tightly placed overlapping acacia leaves on all sides. The nest measured ±250mm in length, with an entrance hole of ±45mm in diameter.

The nest of TPIC4/08 was located in secondary forest, ±530mm above the ground in a recess on the side of a ±750mm diameter decaying log, and was concealed amongst dense vines. Again the nest consisted of a ball of dense teased fibers surrounded by four to five layers of overlapping leaves. The nest measured ±240mm in length, had an entrance-hole ±55mm diameter (Figure 4.7) and had ±10mm thick teased fiber walls (Figure 4.8). All nests that were constructed entirely within hollow logs (n=4) consisted only of teased fibers, with no overlapping leaves being present.

Figure 4.7: Nest of painted treeshrew *(Tupaia picta)* TPIC4/08 constructed against a decaying log. Note all vines and live foliage have been cleared away by field staff (Photograph A. Shadbolt 2008).

Figure 4.8: Cross section cut through nest of a painted treeshrew *(Tupaia. picta)* TPIC4/08 showing ±10mm thick wall of teased fibers surrounded by overlapping leaves (Photograph A. Shadbolt, 2008).

Daily Activity: TPIC4/08 was photographed twice by a camera trap on two consecutive mornings leaving its nest site at 0632hrs and 0627hrs respectively, and TPIC6/08 was recorded by direct observation leaving its nest site in SCF at 0607hrs; the earliest by 20 minutes of any recorded in this study. At the KNF sites, painted treeshrews were recorded leaving their nests on 12 occasions, and returning on 15 occasions (Table 4.5). At this forest, all treeshrews left their nests within a 20 minute window between 0627hrs and 0647hrs.

Return times to nests were more variable ranging from as early as 1620hrs (TPIC1/09) to as late as 1758hrs (TPIC2/09). No significant difference between sexes was detected for the times animals left nests (*t*-test: P = 0.3904), however the female *T. picta* (TPIC1/09) was found to return to a nest and cease activity significantly earlier than the two males (TPIC2/09 and TPIC3/09) at KNF (*t*-test: P = 0.0020). Average daily activity periods were therefore lower for TPIC1/09 (Mean 9hrs/56 minutes) compared to those of the two males (Mean 10hrs/46 minutes and 10hrs/36 minutes respectively). This difference in length of daily activity was also found to be significant (*t*-test: P = 0.0008).

Table 4.5: Daily activity periods for painted treeshrews *(Tupaia picta)* at the Samarakan Conservation Forest and Kakus Nursery Forest.

Animal	Date	Leaves Nest	Enters Nest	Activity Period
TPIC4/08 (Female)	28/03/09	0632[+]	-	-
	29/03/09	0627[+]	-	-
	MEAN	***0630***		**-**
TPIC6/08 (Female)	29/10/08	0607*	-	-
TPIC1/09 (Female)	03/08/09	0639	1638	9hr/55min
	04/08/09	0642	1620	9hr/38min
	05/08/09	0639	1647	10hr/6min
	06/08/09	0639	1641	10hr/2min
	07/08/09	0634	1633	9hr/59min
	MEAN	***0638***	***1636***	***9hr/56min***
TPIC2/09 (Male)	29/07/09	-	1632	-
	31/07/09	-	1738	-
	01/08/09	-	1758	-
	02/08/09	0647*	1750	11hr/3min
	05/08/09	-	1740	-
	06/08/09	0636	1735	10hr/59min
	07/08/09	0629	1653	10hr/22min
	13/08/09	0627	1707	10hr/40min
	MEAN	***0635***	***1725***	***10hr/46min***
TPIC3/09 (Male)	15/08/09	0634	-	-
	16/08/09	0642	1659	10hr/17min
	17/08/09	0627	1721	10hr/54min
	MEAN	***0634***	***1710***	***10hr/36min***

[+] **Camera trap photograph of animal; * Direct observations of animals**

Camera Trapping: At SCF, camera trap DC06 provided images of the radio-collared *T. picta*, TPIC4/08, leaving the nest site on the two consecutive mornings of 28th and 29th March 2009 at 0632hrs and 0627hrs respectively, and an individual *L. insignis* leaving the same nest site on the following morning at 0643hrs (Figure 4.9). Three days later on the 2nd April, the *L. insignis* was photographed returning to the site again on two separate occasions at 1436 and 1733hrs. At KNF on 22nd August 2009, camera trap DC09 captured a single image of TPIC2/09 leaving the nest site at 0635hrs; the mean time of commencement of activity for this animal.

Figure 4.9: Left; radio collared painted treeshrew *(Tupaia picta)* leaving The Samarakan Conservation Forest nest site (0627hrs, 29th March 2009). Right; three striped ground squirrel *(Lariscus insignis)* leaving The Samarakan Conservation Forest nest site (0643hrs, 30th March 2009). Nest is located in cavity at base of termite nest (middle-ground).

In order of frequency, mammal species photographed in the vicinity of *T. picta* nest sites included pig-tailed macaque *(Macaca nemestrina)* (n=4), Bornean yellow muntjac *(Muntiacus atherodes)* (n=3), *T. picta* (n=3), *L. insignis* (n=3), *M. rajah* (n=2), common porcupine *(Hystrix brachyura)* (n=2), common palm civet *(Paradoxurus permaphroditus)* (n=2) and an unidentified murid rodent (n=1). These results are shown in Table 4.6 (below).

Table 4.6: Camera trapping results at painted treeshrew *(Tupaia picta)* nest sites in the Planted Forest Zone, Sarawak, East Malaysia.

Date	Time	Species	Comment
TPIC4/08 Trap DC08 *(Beneath termite nest)*			
28th Mar 2009	0632hrs	*Tupaia picta*	Leaving nest
29th Mar 2009	0627hrs	*Tupaia picta*	Leaving nest
30th Mar 2009	0643hrs	*Lariscus insignis*	Leaving nest
2nd Apr 2009	1436hrs	*Lariscus insignis*	Arriving at nest
2nd Apr 2009	1733hrs	*Lariscus insignis*	Arriving at nest
TPIC4/08 Trap DC09 *(Base of tree)*			
1st Apr 2009	0307hrs	*Maxomys rajah*	In vicinity of Nest
TPIC2/09 Trap DC03 *(Subterranean)*			
20th Aug 2009	1410hrs	*Macaca nemestrina*	In vicinity of nest
20th Aug 2009	2349hrs	*Maxomys rajah*	In vicinity of nest
29th Aug 2009	2043hrs	*Hystrix brachyura*	In vicinity of nest
1st Sept 2009	0436hrs	*Hystrix brachyura*	In vicinity of nest
4th Sept 2009	1837hrs	*Paradoxurus hermaphroditus*	In vicinity of nest
9th Sept 2009	1039hrs	*Macaca nemestrina*	In vicinity of nest
TPIC1/09 Trap DC05 *(Side of log)*			
13th Aug 2009	1301hrs	*Macaca nemestrina*	In vicinity of nest
22nd Aug 2009	2156hrs	*Paradoxurus hermaphroditus*	At nest entrance
TPIC2/09 Trap DC08 *(Hollow log)*			
22nd Aug 2009	0635hrs	*Tupaia picta*	Leaving nest
TPIC1/09 Trap DC09 *(Base of tree)*			
17th Aug 2009	1747hrs	*Muntiacus atherodes*	In vicinity of nest
23rd Aug 2009	2305hrs	Unidentified murid rodent	In vicinity of nest
TPIC1/09 Trap DC12 *(Vine tangle)*			
29th Aug 2009	1222hrs	*Macaca nemestrina*	In vicinity of nest
3rd Sept 2009	1701hrs	*Muntiacus atherodes*	In vicinity of nest
4th Sept 2009	0752hrs	*Muntiacus atherodes*	In vicinity of nest

4.3.2 Dispersal Following Translocation

One male (TPIC5/08) and two females (TPIC1/08 & TPIC2/08) were captured at SCF, fitted with transmitters and released at the novel T1A forest patch. Of these three treeshrews, TPIC1/08 and TPIC2/08 were located daily over 19 days between 26th October and 13th November, and TPIC5/08 was tracked for 16 days from 29th October until 13th November 2008 within three distinct and scarcely overlapping ranges. The total ranging areas for these animals varied greatly from 6.90ha to as much as 24.60ha, however the maximum distance recorded from the point of release was just 560m for TPIC1/08 and 390m for both TPIC2/08 and TPIC5/08 (See Table 4.7). All animals were shown to move into, and in the case of TPIC1/08 and TPIC5/08, reside within acacia forest for a large proportion of their time (92.86% and 76.92% respectively), however no locations were recorded in either acacia or secondary forest that were on the opposite side of the main forest access road.

Table 4.7: Radio tracking results for painted treeshrews *(Tupaia picta)* (28th October – 11th November 2008). Letters in parenthesis indicate the forest type that animals were trapped in, where (F) is secondary forest and (A) is mature acacia.

Animal	Trap Number	No' of Locations Recorded	Locations Recorded in Acacia	Locations Recorded in Forest	Maximum Distance From Release	Range Covered During Study
TPIC1/08 (Female)	1A(F)	14	13	1	560m	24.6ha
TPIC2/08 (Female)	37A(F)	17	5	12	390m	9.1ha
TPIC5/08 (Male)	20B(A)	13	10	3	390m	6.9ha

Following the release of TPIC1/08 at 1115hrs on 26th October, at approximately 1700hrs that day, the animals location was determined from triangulation to be >500m straight-line distance from the release site and approximately 200m from the main plantation access road within seven year old acacia. The following day at 0920hrs, TPIC1/08 was tracked and a confirmed sighting

was made of the animal moving back towards the release patch at speed at a height of 3−4m in the first row of acacia alongside the road. At this point, the animal was approximately 450m straight-line distance from the release patch, however by 1755hrs the animal had moved >300m away from the road and into the acacia again. The following morning at 0855hrs, TPIC1/08 was back within the release patch within 100m of the point of release where it was recorded again that day 1430hrs. Therefore these few locations alone within the first 48 hours of release, would have represented 9.7ha (39.4%) of the total 24.6ha range ultimately used by this animal over the duration of the radio tracking study.

Similarly, following release at 1400hrs on 28th October, TPIC5/08 was located at 0915 the following morning approximately 390m from the release point within acacia. Of the 11 locations recorded for TPIC5/08, nine of these were in acacia, and the remaining two in secondary forest adjoining the release patch. TPIC2/08 exhibited different behavior in that it appeared to favour secondary forest, whereas both TPIC1/08 and TPIC5/08 appeared to spend the majority of their time in acacia. TPIC2 remained almost entirely within the release patch for the duration of its initial 19 day tracking, with the exception of a single recorded excursion of approximately 400m from the release point at 0945hrs on the second morning following release. This location was within acacia, however the animal returned to the release patch by 1800hrs that day where it appeared to remain.

4.4 Discussion

Home Territories: In this study, painted treeshrews were found to use native secondary forest and also mature acacia plantation compartments where they were intermixed with secondary forest. While it is uncertain whether species previously understood to be dependent on natural forest could in fact breed or reproduce in the exotic forest type, or if it was simply used for foraging, Ragai and Tuen (2007) provided evidence that seven year old acacia compartments in the PFZ actually supported a higher species richness of small mammals than did adjacent secondary forest.

This study also illustrates that painted treeshrews occupy large home ranges, similar to those of other Tupaiids studied by Emmons (2000) in Sabah. In her study Emmons recorded mean home range sizes for six Tupaiids, ranging from 1.48 ha for the lesser treeshrew *(T. minor)*, to 10.51 ha for the slender treeshrew *(T. gracilis)* with one individual ranging across an impressive 14.71 ha. This study shows that at a mean 9.11 ha, home ranges for *T. picta* are towards the upper end of the continuum of Bornean treeshrew home ranges (See Table 4.8 and Figure 4.10).

However it is not able to be determined from these and the following comparisons of home range, maximum home range diameter and mean distance travelled per day between species, whether the differences are related to a species effect, a site effect or some other variable (e.g. body size). However despite this uncertainty, and despite the limitation of the small sample sizes reported here being inadequate to form reliable statistical conclusions, the observations provide the only records of this nature for *T. picta*, and provide a basis on which hypotheses can be formulated for further comparative studies.

Table 4.8: Comparison of painted treeshrew *(Tupaia picta)* weights and home range dimensions with those of other treeshrews recorded by Emmons (2000).

Animal	Mass (g)	D max (m)	D min (m)	Total Area Convex Polygon (ha)
Ptilocercus lowii (n = 3)	48	285	189	3.84
Tupaia minor (n = 5)	51	211	111	1.48
Tupaia gracilis (n = 4)	72	535	306	10.51
Tupaia montana (n = 5)	126	271	167	2.28
Tupaia picta (n = 4)	**143**	**398**	**270**	**9.11**
Tupaia longipes (n = 10)	166	530	257	7.94
Mean*	**116**	**368**	**215**	**5.61**

The small sample sizes of both this present study and that of Emmons (2000) make the power to statistically test differences between species weak. However the following tests serve only to demonstrate possible differences that could be used to formulate hypotheses on which to base further studies, pending larger sample sizes for most species. Although statically weak, home ranges differed between species (ANOVA; P = < 0.000) (See Figure 4.10). Compared with tupaiids studied by Emmons (2005), *T. picta* had larger home ranges than the pentail treeshrew, *(P. Lowi)*, lesser treeshrew *(T. minor)*, mountain treeshrew *(T. montana)*, and large teeshrew *(T. tana)*. However home ranges for *T. picta* did not differ from those of slender treeshrews *(T. gracilis)* or long-footed treeshrews *(T. longipes)*.

Maximum home range diameter of treeshrews also varied between species (ANOVA: P = < 0.000) (Figure 4.11) however *T. picta* (Mean 398 m) did not differ from any of the six species listed above (Tukey's pair-wise tests). Maximum home range diameter ranged from being greater than that of *T. minor* (Mean 211 m), to less than that of *T. longipes* (Mean 531 m).

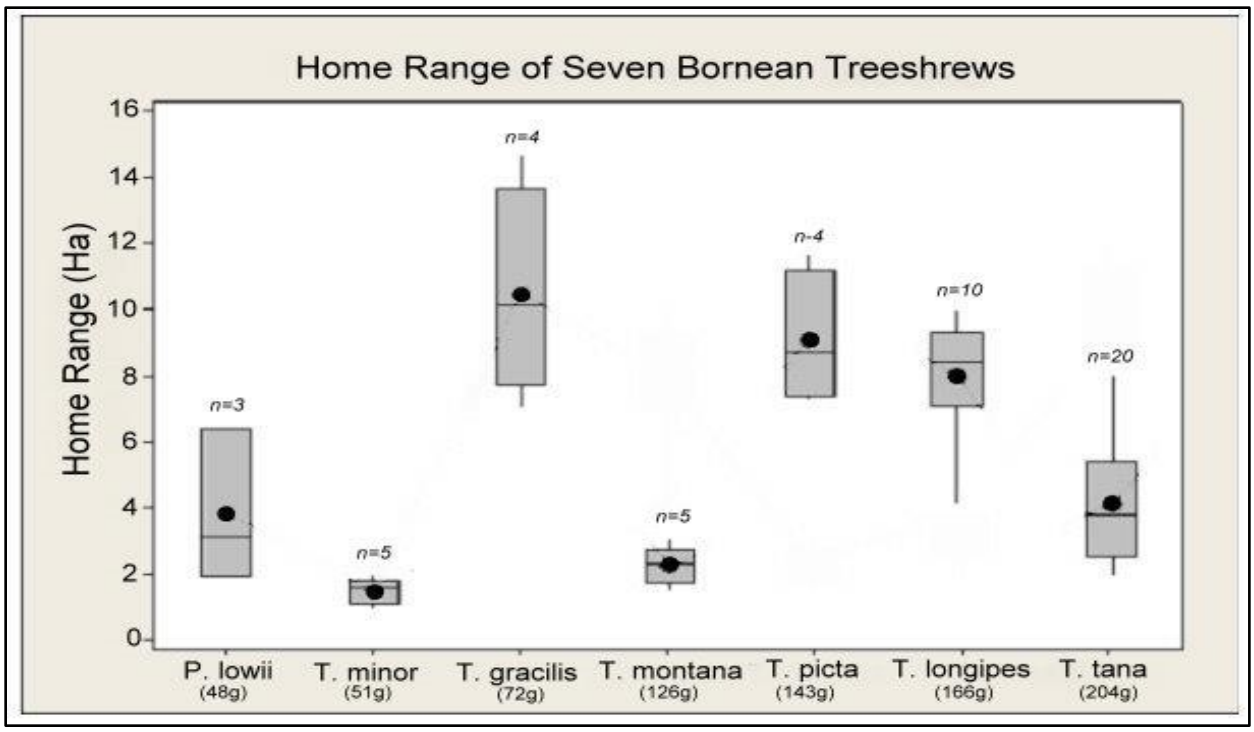


Figure 4.10: Box plot of mean home ranges for six Bornean treeshrews from Sabah, East Malaysia (Source: Emmons 2005), and painted treeshrew *(Tupaia picta)* in remnant forest of the Planted Forest Zone, Sarawak, East Malaysia. Species arranged in order of mean body weight.

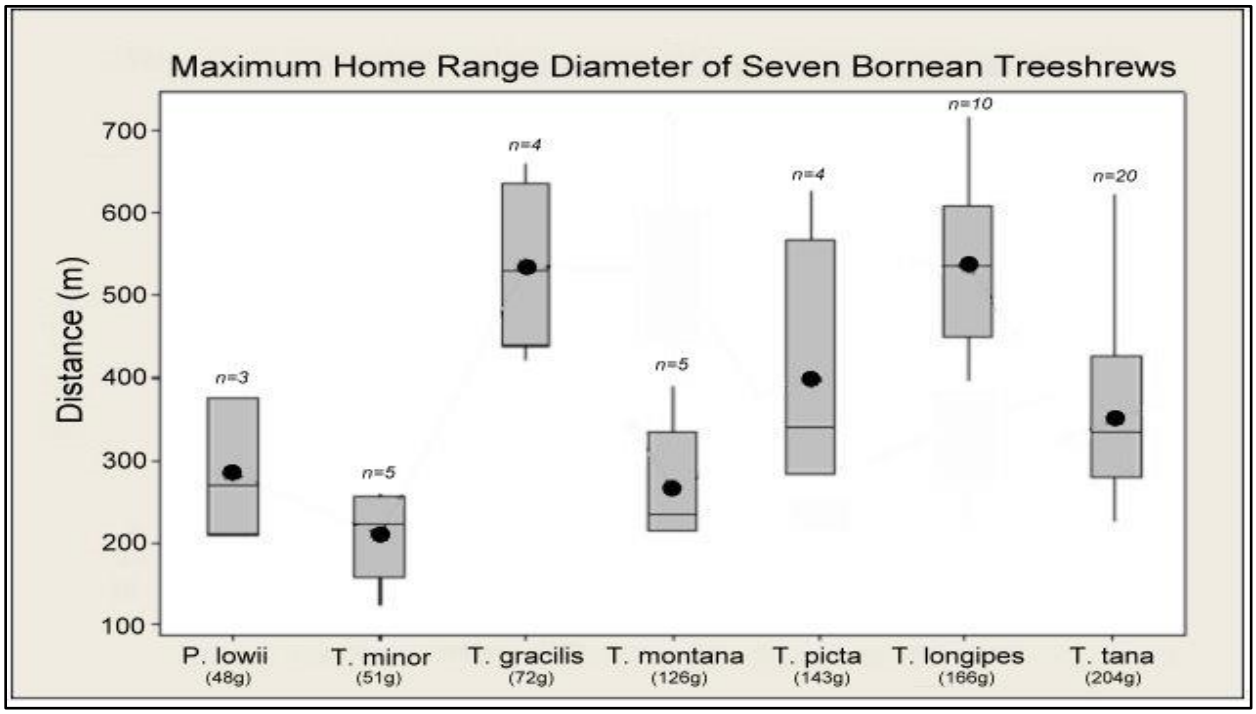


Figure 4.11: Box plot of mean maximum home range diameters for six Bornean treeshrews from Sabah, East Malaysia (Source: Emmons 2005) and painted treeshrew *(Tupaia picta)* in remnant forest of the Planted Forest Zone, Sarawak, East Malaysia. Species arranged in order of mean body weight.

The distances different treeshrew species moved per day was also found to vary between species (ANOVA: $P = < 0.000$) (Figure 4.12), however *T. picta* was not found to vary from any of the other species (Tukey's pair-wise tests). Daily distances for *T. picta* (Mean 1184 m) ranged from being greater than those of *T. minor* (Mean 876 m) to less than those of *T. gracilis* (Mean 1643 m) and *T. longipes* (Mean 1796 m).

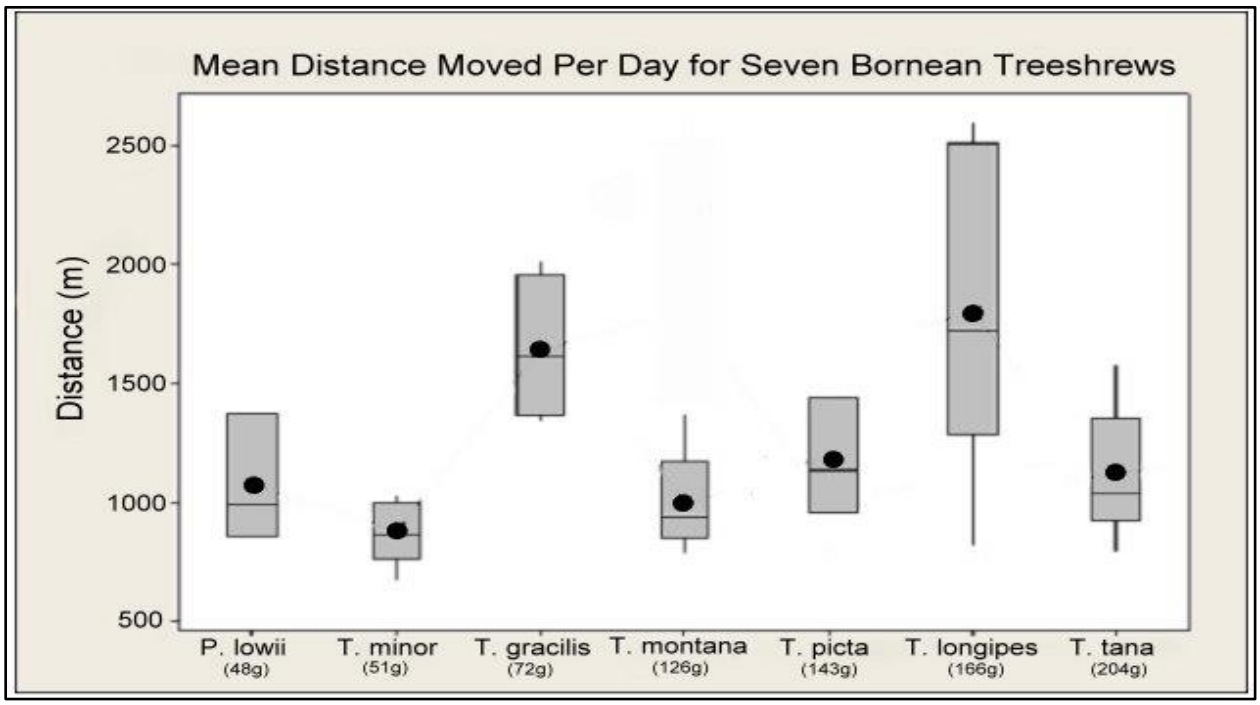


Figure 4.12: Box plot of mean distances traveled per day for six Bornean treeshrews from Sabah, East Malaysia (Source: Emmons 2005) and painted treeshrew *(Tupaia picta)* in remnant forest of the Planted Forest Zone, Sarawak, East Malaysia. Species arranged in order of mean body weight.

It is important to note that a static value for home range is of only limited use due to the inherently dynamic nature of small mammal movements which are influenced by temporal, sexual, reproductive, density, habitat and climatic phenomena (O'Farrell 1978). However by incorporating the results of this and the author's concurrent research (See Chapter 3) in the PFZ, and that of other authors, it has been possible to consider the movement behavior of *T. picta* across a range of spatial scales, thus highlighting a range of issues impacting on the species' ability to thrive in the heavily modified landscape.

In terms of the home ranges of *T. picta*, these were shown to be influenced by the location of forest road networks and other areas of non-habitat such as Samarakan Nursery complex. The recorded home ranges of all three animals tracked in the KNF were found to be constricted by forest roads, where no animals were recorded crossing these features. The same response to forest roads was also recorded where *T. picta* were translocated to the novel forest patch and were not detected crossing forest roads throughout the duration of the radio tracking study.

The barrier effects of roads on wildlife populations have been well documented in the literature (See Bennett 1991), including by Shadbolt and Ragai (2010) for *M. rajah* and in Chapter 3 for *T. picta.* The location of forest roads therefore allows us the ability to predict with a degree of confidence the likely boundaries of home ranges for the local populations of this species, in-turn allowing the ability to more accurately identify defined areas for management purposes which can be incorporated into a more informed population viability analysis.

Painted treeshrews are described as being particularly active in their movements (Hose 1893), and Banks (1931) observed that most treeshrew species spent the majority of their time on the ground on and around fallen tree trunks. As identified in Shadbolt and Ragai (2010) and Chapter 3, non-volant small terrestrial mammals, including *T. picta*, are likely to make significant use of downed woody debris for cover, foraging, as a movement substrate that maximizes travel efficiency, and also for nest construction. This study confirmed the importance of these habitat features for *T. picta* also in terms of nest site location.

Although treeshrews are strongly insectivorous, they also supplement their diets with fruit, and have been observed to spend much of their day around fruit trees, favoring figs where present (Emmons 2000). This pattern of movement reflects the clustered activity patterns observed in

treeshrews tracked by radio telemetry at KNF. Tupaiids may therefore act as seed dispersers, helping to regenerate fruiting trees in the forests they inhabit, as identified by Shanahan and Compton (2000) for *Tupaia tana*.

Optimal foraging theory assumes that an organism will search for food in a manner that maximizes its energy intake whilst expending the least amount of time and energy and in doing so raise the individuals' fitness more than alternative foraging strategy would (Pough *et al.* 1989; Alcock 1993; Smith 1996). Smith (1996) identifies a set of four decision rules central to optimal foraging theory: 1) that consumers will concentrate their foraging activity in the most productive patches, 2) that they will remain in the patches until the profitability of the patch falls to a level equal to the mean for the greater foraging area, 3) they will monitor alternative patches and vacate the present patch once it has been reduced to the level of mean productivity, and 4) will ignore patches of low productivity. Thus two distinct patterns of behavior can be observed: 1) monitoring and traveling between patches, and 2) feeding within them (Arditi and Dacorogna 1987).

At a broad scale, intensive radio tracking has illustrated a clustered use of forest habitat. This pattern of behavior reflects the intensive use of discrete food resource patches, followed by movement to another resource-rich patch once the depletion of food resources within the initial patch has decreased to mean productivity. However while this pattern fits with that of Smith (1996) and Arditi and Dacorogna (1987) as described above, direct observation of study animals (E.g. Emmons 2000) was not undertaken in this study in order to ensure that animal behavior was not influenced by the presence of the observer (Prevett 1991). Therefore the suggestion of exploitation of food resources remains speculative as it was not possible to determine whether animals were actively foraging within the clustered location or if they were resting. However

Emmons (2000) suggests that three species of terrestrial treeshrew; *T. tana, T. longipes* and *T. gracilis,* behaved in similar manner to the arboreal *T. minor* which spent long periods of time at or near fruit trees, and made multiple visits to the trees each day. In the KNF patch the spread of location points within the clusters indicates that fine scale movement was occurring and was further supported by varying signal strengths within the clusters. Therefore a possible explanation is that individuals were alternating both foraging and resting behavior within the clusters.

Nest Sites: Other studies (e.g. Boonstra & Craine 1985, Briani *et al.* 2001, Miles *et al.* 1981, Wells *et al.* 2006) have used spool-and-line devices to locate the nest sites of small mammals. The author has used the spool-and-line method as part of other studies (e.g. Shadbolt and Ragai 2010, and Chapter 3 of this thesis), however to-date just one Tupaiid nest; large treeshrew *(T. tana)*, has been located using the method. However, this low detection rate is likely to be more related the study animals being released mid-morning than to the inadequacy of the method itself. Indeed if animals were fitted with tracking spools and released nearer to their modal time of retirement, one could be more confidant of a higher probability of nest site location, assuming that the spool devices remained attached to the animals. However, while the spool-and-line technique is a significantly cheaper method than radio-tracking, a main drawback for species like treeshrews that have multiple sleeping sites is that for each capture, just one nest can be located as opposed to the potentially large number of nests that can be located over a period of many months using radio collars. Having said that, the low-tech/low cost nature of spool-and-line tracking may be ideally suited to wildlife research projects in developing countries like Malaysia where funding for such projects may be scarce or at the very least highly contested between competing projects.

Often the importance of food sources tend to be overemphasized in terms of the survival of individuals in forest habitats (Moraes Jr. and Chiarello 2005), while other important resources such as sleeping sites can be overlooked. This study illustrates the importance of large diameter dead wood to *T. picta* occupying secondary forest fragments and also acacia plantation compartments of the PFZ. The likely competition from other Tupaiids (see Emmons 2000b) and squirrels for suitable nest sites further reinforces the need to manage the large diameter tree and deadwood resources sustainably in order that potentially vulnerable species; as common as they may be at present, are maintained at viable population levels across the landscape and throughout the working life of the plantation.

Tupaia picta appear to be opportunistic rather than obligate users of both tree cavities and hollow logs for nest sites; similar to other Tupaiids (see Robinson and Kloss 1909; Lyon 1913; Emmons 2000b). While they appear to prefer these features, they are shown to also use nests constructed in or on other substrates including below ground and in relatively exposed situations. However use of more open nest sites may expose animals to increased risk of detection and predation by olfactory predators (Conover 2007) which may help explain why just one of the 24 nest sites found (4.17%) was located in such an exposed situation.

In terms of olfactory predators, marbled cats *(Felis marmorata),* leopard cats *(F. bengalensis)* and clouded leopards *(Neofelis nebulosa)* are reported by Emmons (2000b) to be among the only predators of adult treeshrews, while birds of prey were the biggest threat to young. Mongooses *(Herpestes* sp*),* civets (Viverridae), reptiles and invertebrates were also reported to feed on nestlings. All three felids and a short tailed mongoose *(H. brachyurus)* have been recorded within the vicinity of SCF from camera trapping inventories, along with direct observations of short tailed mongoose, collared mongoose *(H. semitorquatus),* Malay civet *(Viverra tangalunga)*

and yellow-throated marten (*Martes flavigula)* (Giman *et al.* 2007). While only limited camera trapping has been carried out to-date in the vicinity of KNF, it is assumed that the same predatory species would also occur at this location. The only potential treeshrew predator recorded on camera traps in KNF was the common palm civet *(Paradoxurus hermaphrodites)*; however during fieldwork civets and a yellow-throated marten were observed in the vicinity, along with birds of prey and a cobra.

Emmons (2000a) describes adult treeshrews as having a strong musky odour, and observed that while such an odour may expose them to increased risk of predation by olfactory predators (e.g. yellow-throated martens), no human-detectable odour was experienced at nursery nest sites, possibly due to the absentee parental behaviour. In this present study it was noted that sleeping nests of *T. picta* were also clean and odorless to human olfactory senses, and as with the Bornean treeshrews studied by Emmons (2000), *T. picta* was also found to use multiple nest sites dispersed widely throughout its home range. The 'clean' condition of these nests may be the direct result of the frequent nest shifting behavior displayed by this and other treeshrew species; a strategy adopted by treeshrews that, as well as preventing the build-up of odor, may also reduce parasite prevalence (Wells *et al.* 2006), and also avoid the creation of well-worn run-ways leading to nest entrances which would otherwise inform visual predators of their location (Emmons 2000b).

A lower occurrence of trees with natural hollows in secondary forest patches and plantation compartments compared to primary forest may largely be a result of successive selective harvesting and forest clearance practices respectively (see Meijaard and Sheil 2008); practices that greatly simplify key aspects of stand structural complexity (Lindenmayer *et al.* 2009). Acacia compartments in the PFZ were found to be most lacking in these key structural elements

(unpublished data), and the distribution and population density of species like *T. picta* that may largely depend on tree cavities and/or large diameter coarse woody debris may be limited by their availability (Wells *et al.* 2006).

Inter-specific Nest Sharing: Although the Bornean Tupaiids use nests of relatively similar construction, biologists have suggested that treeshrews may not construct their own nests, but instead use nests constructed by other species (Hose 1893; Wharton 1950; D'Souza 1972; Emmons 2000b). Emmons (2000b) identifies that the nests of Malaysian squirrels are of a similar construction to those of treeshrews, and although squirrel nests are also constructed with a lining of teased strips of bark and fiber, information on the nests of sympatric squirrels is lacking and the question still remains as to whether the nests are constructed by the treeshrews or squirrels.

Although an example of inter-specific nest sharing has been reported by Wells *et al.* (2006) for *M. rajah* and the long tailed giant rat *(Leopoldamys sabanus)* in Sabah, until now no published works have documented possible inter-specific nest sharing between treeshrews and other species such as squirrels. Although the use of the same nest site by *L. insignis* and the *T. picta* still gives no clue as to which animal constructed the nest, it may indicate that competition for nest sites could exist between these and possibly other species also. However further evidence would be required to ascertain any real limitation in the availability of nest site resources that would lead to this type of competition.

While the incidence of possible nest sharing between *T. picta* and *L. insignis* consisted of a single anecdotal observation, it was an unexpected but interesting finding. The inter-specific overlap in nest site usage raises interesting questions regarding the relationship between these

two species, both of which are absent from Sabah and northern Kalimantan (Payne and Francis 2005), have both have been trapped in the PFZ, yet neither were recorded by Nakagawa *et al.* (2007) during trapping in the Lambir Hills National Park despite being within the natural range of both. Regardless, this is the first reported incidence of nest sharing between these two species and warrants further investigation which could be achieved through a longer duration camera trapping study at confirmed nest sites of both species and other locally occurring Tupaiids (See Chapter 5). Such a study would also provide more robust data on how often, and at what regularity different nest sites were used across the animal's home range.

Daily Activity: At two study sites in Sabah, East Malaysia, Emmons (2000b) observed that individuals of all *Tupaia* species left their nest sites in a tight temporal cluster between 0545 and 0605hrs. In Peninsula Malaysia however, D'Souza (1972) recorded a much later commencement of activity (0745hrs) for *T. minor*. In this present study *T. picta* were recorded leaving nest sites in a tight cluster between 0627 and 0647. However as the study site was approximately 370km and 530km respectively west of Emmons' study sites at Poring and Danum Valley, this may account for the later commencement of activity. Furthermore, as both Peninsula Malaysia and East Malaysia share the same time zone, this may also help explain the even later commencement of daily activity recorded for *T. minor* by D'Souza (1972) in Peninsula Malaysia which lies >1500km to the east of Sabah.

However Giman *et al.* (2007), using camera trapping to perform an inventory of mammals occurring in the PFZ, recorded activity of Tupaiids that suggests at least some species in this part of Sarawak may leave their nest sites as early as the times reported by Emmons (2000b) in Sabah. Their study recorded activity of *T. longipes* at 0635, *T. tana* as early as 0612hrs. As the

camera traps used in their inventory were not intentionally located at treeshrew nest sites, it can be assumed that these detection times are later than the actual times of emergence from the nests.

Although Emmons (2000b) indicated that treeshrews tended to leave their nest sites just as the first rays of sunlight reached the forest floor in her study area, this phenomenon was difficult to study on my study site due to the different canopy densities throughout the more patchy forest, especially when detecting the commencement of activity remotely. It is interesting to note from the results presented here that both direct observations of treeshrews leaving nest sites represent the earliest by 20 minutes and the latest by five minutes of any animals leaving the nests during the study. There is a possibility therefore, that the presence of the fieldworkers in the immediate vicinity of the nest may have been detected by the animals and that this may have influenced the animals' behavior. Indeed on a number of occasions individuals of *T. picta* fled their nests when fieldworkers approached shortly after they had retired for the day. This flight response almost never occurred after the treeshrews had been retired for several hours before fieldworkers approached nest sites.

Population Viability: Species populations with negative long-term growth rates will require constant management to prevent their extinction (Holsinger 2000), however the ability of populations to persist in a fragmented landscape will vary between species depending on their ability to use and move easily through the matrix. The simple PVA using VORTEX software demonstrated the value of patch size and metapopulation dynamics in providing suitable habitat for *T. picta*. Based on the assumptions listed in Table 4.1, and on estimates of home range size determined from this study and the resulting patch carrying capacity, neither the SCF nor the smaller Kakus West patch were found to be large enough to sustain viable populations of *T. picta*

in the long-term. However the Kakus East patch and the entire KNF forest, when considered as a single entity, were found to offer significant probabilities of long term persistence.

The scenarios modeled allowed for consideration of populations as being both closed and open. However VORTEX was limited in its ability to account for both the ambient immigration and dispersal to and from the matrix, and the temporal and spatial dynamics of plantation harvest and subsequent re-establishment. However immigration to patches was able to be included in the model by 'supplementing' the population at seven-yearly intervals (i.e. the interval between successive plantation harvests). While the ability of *T. picta* occupying the acacia matrix to locate remnant patches during plantation harvest is at present unknown, the immigration scenarios modeled here demonstrate the possible advantages of facilitating such dispersal which was shown to be particularly important for decreasing the probability of extinction at the SCF patch. Therefore further field research into this phenomenon is warranted, and is discussed further in Chapter 5.

Although the PVA for the SMC forest patch indicated very low probabilities of survival even with an increase in carrying capacity and allowance for immigration during plantation harvest, inventories carried out in the forest patch have consistently found *T. picta* present despite repeated removal trapping (Refer Chapters 2 and 3). Furthermore *T. picta* have been trapped in mature acacia forest immediately adjacent to the SCF, and were recorded making extensive use of mature (> seven year old) acacia during both the spool-and-line tracking (Chapter 3) and radio tracking studies reported here.

While *T. picta* were observed to use mature acacia forest, it is unknown whether they will enter young acacia compartments. If these animals are not able to utilize young acacia forest, remnant

native forest patches that are isolated within the acacia matrix may remain isolated from neighbouring patches in terms of the dispersal ability of *T. picta* until such time the acacia stand matures. In the case of the SCF patch it is possible that a remnant population of *T. picta* became isolated within the forest patch at the time of forest clearance, and subsequently dispersed into the acacia plantation as it reached maturity, thereby expanding the available habitat and corresponding population size of the deme. In this sense the current extent of *T. picta* habitat in the SCF area is likely to be far greater than the extent of the natural forest (c.77.50 ha).

Unfortunately the acacia grown in the PFZ is intended to be harvested on a seven year rotation, and it is therefore unlikely that the full benefits of a mature acacia forest capable of providing suitable habitat for *T. picta* will be realized under this management regime. Therefore, following harvest of the over-mature acacia adjoining the SCF patch, the total habitat available to *T. picta* is likely to return to c.77.50 ha, which as discussed above may be unlikely to provide for a viable population of the species in the long term in the absence of re-colonization from adjacent patches.

Animals are generally reluctant to expend energy and expose themselves to the increased risks associated with dispersal over multiple home range diameters (McComb 2008), and as a consequence small mammals may be unlikely to disperse more than twice the width of their home range during a single dispersal event. Therefore in order for the SCF to function as part of a wider metapopulation, a second population of *T. picta* should be within close proximity of the SCF if re-colonization of the forest from a neighbouring patch following a local extinction is to be successful. The nearest large patch likely to be capable of supporting multiple *T. picta* home territories is 1500 m to the north east. As the mean maximum diameter of *T. picta* home ranges was found to be less than 400 m, this implies that they would need a neighbouring forest patch to

be within 800 m of the SCF patch in order to facilitate a minimum degree of dispersal between patches to maintain metapopulation dynamics. While this is only a rule-of-thumb estimate of maximum patch separation distance, it is useful as it provides a baseline for planning, design and management of landscape level patch configuration for this species in the absence of more accurate data.

Movement in Novel Patches: While the animals were shown to be capable of moving long distances in short periods of time, none were observed to have dispersed more than 560m (TPIC1/08) from the point of release over the duration of the study, and the variations recorded in total area used appeared to be largely a result of initial exploration of the novel environment in the first few days post-release. Similarly, red squirrels *(Sciurus vulgaris)* reintroduced to novel woodlands at Parco Regionale delie Groane, northern Italy, were shown to cover considerable distances in the first two weeks post-release. Regular long distance excursions in the initial exploring phases were found to be responsible for the large overall ranges observed before individuals settled into their smaller sized home ranges. As with *T. picta*, individuals of *S. vulgaris* were found to settle into almost exclusive core areas with little overlap showing a strong degree of intra-specific avoidance (Wauters *et al.* 1997).

In contrast, Innes *et al*. (2007) found that radio collared ship rats *(Rattus rattus)* released into novel habitat into Maungatautari forest sanctuary, New Zealand, tended to remain within 100 m of the release site for three days before making wider ranging movements. Similarly, brown spiny rats *(Maxomys rajah)* radio collared by the primary author and released into the same novel patch as the *T. picta* of this study were not found to disperse more than 275m from their points of release for the duration of the study period (unpublished data).

Both TPIC2/08 and TPIC5/08 were observed to have moved maximum distances of just 390m from the site of release. This could be attributed to a reluctance of the animals to expend energy and expose themselves to the increased risks associated with dispersal over multiple home range diameters (McComb 2008), where the mean maximum and minimum diameters of the home ranges of the five Tupaiids (see above) recorded by Emmons (2000) were 379.12m and 209.32m respectively. However a decision not to disperse across greater distances may result in an animal taking up a new home range in supposedly sub-optimal habitat such as that offered within acacia plantation as seen here in the cases of TPIC1/08 and TPIC5/08.

The radio telemetry study illustrated the distance that *T. picta* is capable of travelling in novel environments, and also the speed at which such travel can occur This was also supported by the direct observation of an animal moving at speed through the low branches of acacia, and in-turn supporting supports Emmons' (2000) observation that treeshrews bound with springing leaps from sapling to sapling as well as ferreting slowly along the ground (as suggested by the spool and line tracking). However although *T. picta* was found to move considerable distances in relatively short timeframes, these estimates are likely to be conservative in terms of the 'actual' distance travelled given that animals tend to zigzag (Emmons 2000) rather than travel in straight lines. From analysis of the spool and line paths (Chapter 3) I found that the mean path length was 160% (116−259%) longer than ten-meter increment straight line sections measured along plotted paths. This would therefore mean that TPIC1 may have actually travelled more than 800m, or even 1295m if the upper value is applied, as opposed to the recorded 500m in less than six hours following release. These movement rates of between 87 meters per hour (500m) to 225 meters per hour (2295m) fall within the movement rates for other Tupaiids recorded by Emmons (2000) in Sabah. In that study lesser treeshrews *(T. minor)* were found to move at mean rates of 83

meters per hour, slender treeshrews *(T. gracilis)* 151, common treeshrews *(T. longipes)* 178, mountain treeshrews *(T. Montana)* 84, and large treeshrews *(T. tana)* at 105 meters per hour within their own home ranges.

Conclusions: This study had provided valuable new insight into a species for which comparatively little was known in terms of its ecology and behavior compared with the other Bornean tupaiids, and also represents the first radio telemetry study to be carried out in Sarawak. While the prognosis for *T. picta* in the PFZ looks promising from the results of this study; particularly if remnant forest patches are maintained in an optimal spatial arrangement at the landscape scale, the inclusion of common species such as the *T. picta* in monitoring programmes is important in ensuring that trends are identified early on.

Meijaard and Sheil (2008) emphasise that in order to successfully sustain biodiversity in heavily managed landscapes such as those of fast-growing timber plantations, good management practices are required, incorporating the current pool of scientific knowledge relating to species vulnerability into forest management interventions. To this end, the findings of studies like those reported here, and the myriad of related studies, both published and un-published, need to be incorporated into forest management plans and policies. However regardless of policy, the key to ensuring such initiatives are executed on the ground may largely rely on the transfer of knowledge, along with an appreciation of the value of both wildlife and their habitat requirements, to plantation staff across all levels of the organization.

Therefore there is a critical need for monitoring programs that inform conservation efforts based on changes or trends in a species' status, and such monitoring programs should target both rare and common species alike (Nielsen *et al.* 2009). This will help ensure that common species like

the painted treeshrew are maintained while their status is still described as common rather than relying on complex protection and recovery interventions where a species has already markedly declined before such interventions are implemented.

CHAPTER 5

Synthesis

5.1 General Discussion

In terms of disturbance and changing environmental conditions, (see Chapter 1) the name Borneo itself evokes a vision of not only its luxurious rainforests, but also of a constantly changing landscape (Potter 2006). For Sarawak, faced with the reality of its diminishing natural forest resources (Poore 2003), plantation forestry is likely to continue to be a permanent fixture of the landscape. However it is within these large-scale, fast-growing industrial timber plantations that the opportunity exists to provide not just for economic growth and community development, but also for the conservation of biological diversity on a broad landscape scale; an opportunity not likely to be possible under a regime of smallholder land ownership or in the current limited extent of the State's Totally Protected Area network.

Aside from habitat loss, one potentially major threat to wildlife species, particularly mammals, is the fragmentation of habitat (Verboom and Apeldoorn 1990; Gaines *et al.* 1997; Zollner 2000; Bakker and van Vuren 2004; Strevens 2007; Lees and Peres 2008; Mortelliti *et al.* 2009; Mortelliti and Boitani 2008; Holland and Bennett 2009; Shadbolt and Ragai 2010; Charles and Ang 2010) and the consequent isolation of populations within the fragments (see Chapters 3 and 4). For many wildlife species that are dependent on natural forest for their persistence, the fragmented state of the remaining natural forest patches in the PFZ will mean that they are isolated within relatively small habitat patches. In the absence of an ability of these species to disperse between patches, their populations are likely to remain precariously small and prone to local extinction.

With the extinction of successive isolated populations, over time this could conceivably result in the area-wide extinction of species that are demonstrated to be intolerant of fragmentation.

However with good management and broad scale landscape level planning it is anticipated that a landscape mosaic composed of acacia plantation compartments, conservation set-asides (wildlife corridors, stream buffers, steep land, remnant patches), and the preservation of fine scale landscape features (standing deadwood, decay cavities, downed woody debris, mixed age compartments) will mean that a representative sample of the areas original biodiversity is likely to be able to persist in the long term. Where some species may be capable of exploiting and even residing permanently within the acacia matrix, others that are less tolerant of this novel environment may still be able to persist at the landscape level as a metpopulation; a series of semi isolated populations (demes) that become extinct and are re-populated following dispersal and emigration from a neighbouring patch.

Notwithstanding small sample sizes and the resulting inability to apply rigorous statistical tests in some instances, the findings presented in this thesis have provided a significant contribution to the body of knowledge on the behaviour of small mammals in heavily fragmented landscapes on Borneo. Moreover this research has applied both novel experimental and observational approaches to studying these little-studied species in an even more poorly understood plantation environment that is fast becoming the dominant land-use across Borneo. Therefore despite the limitations of the experimental approaches reported here, the detailed observational records provide another appropriate and important means of contributing significantly to the knowledge and understanding of these species, particularly given how little is known of their ecology and behaviour in natural forest habitats, much less plantation landscapes.

Species Diversity and Abundance: The small mammal trapping sessions reported in Chapter 2 of this thesis illustrated some possible trends that may help inform plantation establishment and management in environments like those of the PFZ. Unfortunately the sampling protocols used

during this study were not robust enough to arrive at firm conclusions regarding the relationships between patch size and species diversity and abundance, however in the absence of more robust data for the PFZ, the results reported here could be used to support a precautionary approach to landscape management.

The precautionary approach is likely to be an important management tool in situations where forest managers do not have the benefit of being able to wait until long-term and often expensive data are available to support management decisions. In developing countries such as Malaysia, and particularly in states such as Sarawak where forest conversion is occurring at a rapid pace, managers are in desperate need of guidance of this nature. Therefore while some of the results reported here are statistically inconclusive, they do suggest trends that could be validated with a more robust study, but could still be used to inform the precautionary approach until such time that more robust data are available.

Based on the findings of this study, and notwithstanding the caveats described above and in Chapter 2, small forest patches of c.1 ha (e.g. Figure 5.1) that are exempt from clearing during plantation establishment may remain species poor and host small populations of extant species only. Medium sized patches exhibited the greatest species diversity and abundance, whereas the largest forest areas hosted the largest population of brown spiny rat *(Maxomys rajah);* a species that is identified as vulnerable by the IUCN across its natural range (Alpin *et al.* 2008).

The protection and maintenance of forest patches larger than c.5 ha may be critical in the persistence of non-volant small mammals across the PFZ landscape given that this sized patch hosted as many species as did the largest forest patch (>500 ha), albeit at much reduced abundance. Thus even these relatively small forest patches are likely to have some value to some

species, whether they are providing core habitat for forest dependant species like *M. rajah*, or as a resource patch as part of a more extensive home range for wider ranging species like the painted treeshrew *(Tupaia picta)* that may exploit several such patches within their range (e.g. Sitompul 2004). However regardless of their relative merits for small non-volant mammal conservation in the PFZ, even very small remnants of native forest are assumed to have important biodiversity conservation benefits to other areas of biodiversity (e.g. invertebrates, flora, herpetofauna).

Figure 5.1: Remnant patches preserved following harvest of plantation compartments, Planted Forest Zone, Sarawak, East Malaysia (Photograph A. Shadbolt 2011).

Response to Habitat Fragmentation: In terms of a species response to habitat fragmentation and habitat edge features reported in Chapters 3 and 4, this study has illustrated the differences in behaviour and response of a range of non-volant small mammals to these phenomena; most notably the presence of forest roads and the acacia plantation compartment matrix. Moreover it has provided evidence that for some species forest roads and the acacia matrix may represent

significant barriers to animal movement and dispersal, while for other species acacia compartment edges may be moved across with relative ease *(i.e. T. longipes* and *T. picta*). Thus different species were shown to perceive their landscapes very differently from one-another, and the inability for animals to move through the matrix may also prevent the dispersal of plants and their pollination between patches where the animal species is a seed disperser or pollinator (Turner 1996).

Areas of tree plantation have the ability to provide valuable corridors between forest fragments (Turner 1996), however a species' vulnerability in these fragments is directly related to their ability to use modified habitats (Gascon 1999) such as the plantation matrix. Understanding how different species are likely respond to these matrix habitats is essential for managing landscapes that are dominated by human activity. This is especially important in tropical forest ecosystems where conversion to agriculture and plantation forestry is spreading rapidly and often in an unplanned manner (Umetsu and Pardini 2005). Thus understanding how species are affected by fragmentation necessitates information on their responses to all components of the landscape (Gascon *et al.* 1999), including in this case a matrix of short rotation acacia plantation.

Small mammals with low dispersal and colonisation ability are likely to be more exposed to the adverse effects of forest fragmentation, thus reducing their persistence in fragmented landscapes and highlighting the importance of functional landscape connectivity (Rocha *et al.* 2011). Species that avoid matrix tend to decrease or disappear from forest fragments, while those that are able to tolerate or exploit the matrix can remain stable or even increase in abundance (Gascon *et al.* 1999). For example Mena and Medellin (2010) reported a greater abundance or marsupials in a small fragment in a disturbed Peruvian forest landscape compared with a large fragment. However small forest fragments often have fewer species recorded than larger patches or

continuous forest for the same effort of observation, having suffered reductions in species richness over time since being isolated from a once continuous forest (Turner 1996).

Although large areas of continuous primary forest are likely to be of critical importance for many forest species (Barthlott *et al.* 2001; Floren and Linsenmair 2005; Gibson *et al.* 2011; Heinen 1992; Kessler *et al.* 2005; Turner *et al.* 1997; Vulinec 2006), Gascon et al. (1999) recorded a surprising number of species capable of using matrix habitats when large continuous tracts were nearby to provide a source of immigrants. It is therefore not always appropriate to use the term matrix in relation to the habitat type surrounding a forest fragment, as the term matrix can imply that the alternative land use type is inhospitable to a species (Ewers and Didham 2006). In the cases of *T. picta* and *T. longipes*, there is evidence from the spool-and-line tracking (Chapter 3) to suggest that these species spill over into the acacia 'matrix', possibly using it as additional habitat. For *T. picta* this finding is backed up with evidence from radio tracking (Chapter 4) where all animals released into novel patches were found to make extensive use of acacia. Therefore the terms patch, matrix and corridor need to be applied with degrees of caution.

Rocha *et al.* (2011) found that a low species richness found in a coffee plantation matrix in Brazil compared to nearby forest patches and corridors was the result of low structural complexity in the plantation matrix. Umetsu and Pardini (2005) also recorded a low probability of most endemic tropical small mammals occupying altered habitats including homogenous eucalypt plantation. However the matrix will often act as a selective filter rather than an absolute barrier to movement of species across landscapes (Gascon *et al.* 1999). Passamani and Ribeiro (2009) and Rocha *et al.* (2011) both suggest that the low rates of small mammal recapture in two respective coffee plantations compared to adjacent forest patches may suggest that individuals use these plantations as dispersal routes, rather than as habitats for those species.

However, movement into and through acacia may entail a higher risk of not encountering another forest patch or otherwise optimum habitat within normal dispersal range. Also, and as discussed in Chapter 4, acacia compartments are lacking in large woody debris that was demonstrated to be extensively used by individuals for movement and cover (Chapter 3) and nest sites (Chapter 4), thus potentially exposing individuals to increased threat of predation. This lack of large woody debris is primarily the result of successive harvesting and forest clearance (see also Meijaard and Sheil 2008), and species dependent on these structural habitat components may be limited in terms of their distributions and population densities (Wells *et al.* 2006a). This reinforces that timber production should not remain the sole value managed for within the matrix (Saunders *et al.* 2000) if viable populations of a range of fauna are to be maintained across the PFZ landscape.

In a translocation experiment in Brazil, similar to this present study, Prevedello and Vieira (2010) found that two species of didelphid marsupials *(Didelphis aurita* and *Philander frenatus)* fitted with tracking spools and released in a manioc (*Manihot esculenta)* plantation matrix more than one kilometre from their home territories tended to orient their movement along plantation rows. In this experiment animals were found to make more movements parallel with plantation rows, where these movements were found to be more linear (less tortuous) parallel with the rows compared to perpendicular movements regardless of whether nearby natural forest fragments were within or outside the animals perceptual range.

In Brazil, manioc (known as tapioca in Malaysia) is an important shrubby perennial crop grown as a staple subsistence food, and also on a plantation scale for biofuel production (Klanarong *et al.* 2012), and therefore represents a very different environment to a plantation matrix composed of acacia. For example in Prevedello and Vieira's (2010) experiment, the manioc plants were

established in parallel rows at approximately 1.60 m centres, and were described as being fully grown at 1.85 m in height. However while this differs markedly from the acacia planting regime in the PFZ where trees are planted at approximately 4.0 m x 4.0 m spacing's, the size and form of the 'mature' manioc may resemble very early rotation acacia compartments.

Therefore, as recommended by Prevedello and Vieira's (2010), if plantation rows in the PFZ could be orientated to maximise functional connectivity between nearby fragments and/or large forest reserves, the dispersal ability of small mammals and other fauna could be enhanced from very early on in the plantation's rotation cycle. However this theory would rely on species occurring in the PFZ exhibiting the same behavioural responses to plantation row orientation as the two didelphid marsupials, and also on the practicality of achieving optimum tree row orientation in hilly landscapes like those of the PFZ. Regardless of these caveats, and in the absence of empirical research of this nature on local species, it seems a promising precautionary strategy that could be easily implemented at no or negligible cost to plantation managers, and could play an important role in maximising dispersal of species across the PFZ landscape.

Corridors: Similarly, not all species are likely to recognise and use linear forest habitats as *'corridors'* in the way humans might perceive them to be used. Likewise these same species may be unlikely to recognise acacia forest as a *'matrix'* that is inhospitable to them, and in the case of species like *T. picta* (refer Chapter 4) may use acacia as an extension of their core habitat.

In contrast, species like *M. rajah* and *T. tana* for whom acacia was shown to represent a potential barrier to movement, may be more likely to use linear forest landscape units as corridors where their movement would remain within, and funnelled along a linear forest habitat. This behaviour is likely to improve the way in which corridors are used by these species compared with more

matrix tolerant species. However where their habitat is provided by an isolated forest patch rather than being connected to a corridor between two or more neighbouring forest habitats, their ability to traverse the matrix may be inhibited. Accordingly, their ability to disperse to a neighbouring patch may be significantly compromised, with adverse implications for functioning metapopulation dynamics.

Roads: Linear landscape features such as roads present a significant barrier to non-volant small mammal species. The adverse impacts of forest roads on wildlife communities has been well reported in the literature (e.g. Bennett 1991; Forman 1995; Forman 2003; Hilty *et al.* 2006; Laurance *et al.* 2004; Merriam 1991; Merriam *et al.* 1989; Rico *et al.* 2007; Shadbolt and Ragai 2010). Roads through tropical forests can cause a suite of effects including habitat loss, edge and disturbance effects, invasive species incursions, road mortality and barriers to dispersal (Goosem 2007). Therefore while acacia plantation compartments may provide functional connectivity between isolated secondary forest patches for some species, the occurrence of forest roads may pose barriers to wider dispersal across the PFZ.

However it would be naive to assert that these species are completely incapable of crossing roads, and the spool-and-line method is clearly limited to a very small window of observation, determined by the length of thread contained within the spool. Therefore while evidence points to roads presenting significant barriers to some non-volant small mammals, the roads more realistically present filters to dispersal rather than absolute barriers. Although studies of *T. picta* dispersal and home range behaviour did not record road crossing behaviour for any individuals of this species, the one incidence of *M. rajah* crossing a forest road is suggestive of such a filter effect where at least some individuals of a population may be capable of, or at least willing to attempt road crossings.

Although this research has not provided evidence for any study species crossing roads with the exception of the single *M. rajah*, Tupaiids have been observed crossing roads by the author and others within the PFZ on a number of occasions. From these fleeting glimpses, the treeshrews observed crossing roads in the PFZ were thought to have been either slender treeshrews *(T. gracilis)* or lesser treeshrews *(T. minor)*; species distinguishable only through hind foot measurement (Payne and Francis 2005).

Rico *et al.* (2007) found that for non-volant small mammals in a temperate forest system, road surface construction did not play a critical role in regulating the crossing ability of study animals where dirt and gravel roads did not differ significantly from paved surfaces of similar widths. They propose that the presence of canopy cover over a road may play an important role in the decision making process of an animal whether or not to attempt a road crossing. Depending on road construction, canopy closure over a small road creates an under-storey environment approaching that of a forest interior (Merriam *et al.* 1989) and the crossing responses of the range of small mammals in this study to abandoned haul trails (e.g. Figure 3.24) lends evidence to this claim.

It is assumed that wildlife would have a higher probability of crossing roads of both decreasing traffic volume and decreasing width (Forman *et al.* 2003). This trend has been observed for a range of temperate forest non-volant small mammals where species were found to readily cross road corridors up to approximately 15 m wide but rarely crossed roads between 15 and 30 m wide (Oxley *et al.* 1974). However several studies have revealed crossing probabilities of less than 10% of that for movement in surrounding habitats even for lightly travelled roads 6 – 15 m wide (Mader 1984).

Therefore where main forest roads are required to pass through wildlife corridors (e.g. Figures 3.23 5.2 and 5.3), although an acacia edge-sensitive individual may have been able to move along the corridor, its movement is likely to be inhibited by the presence of the road. This could limit or sever gene flow by dividing populations on either side of the road (Mader 1984; Merriam 1989), resulting in a series of isolated patches rather than a single large patch hosting a single large population. The home range behaviour of *T. picta* (Chapter 4) is illustrative of this effect. However where there is a small probability of the patches receiving immigrants from across the road corridor, although the patch still remains semi-isolated it has the ability to function as part of a wider metapopulation (Refer Chapter 4).

Unfortunately it is practically impossible in most situations for forest roading engineers to avoid crossing conservation corridors (E.g. Figure 5.2), particularly when the economics of doing so may make commercial operations unviable. Therefore it is imperative that conservation professionals work in close collaboration with forest roading engineers and planners to ensure that any adverse impacts of forest roads are minimised and/or appropriately mitigated.

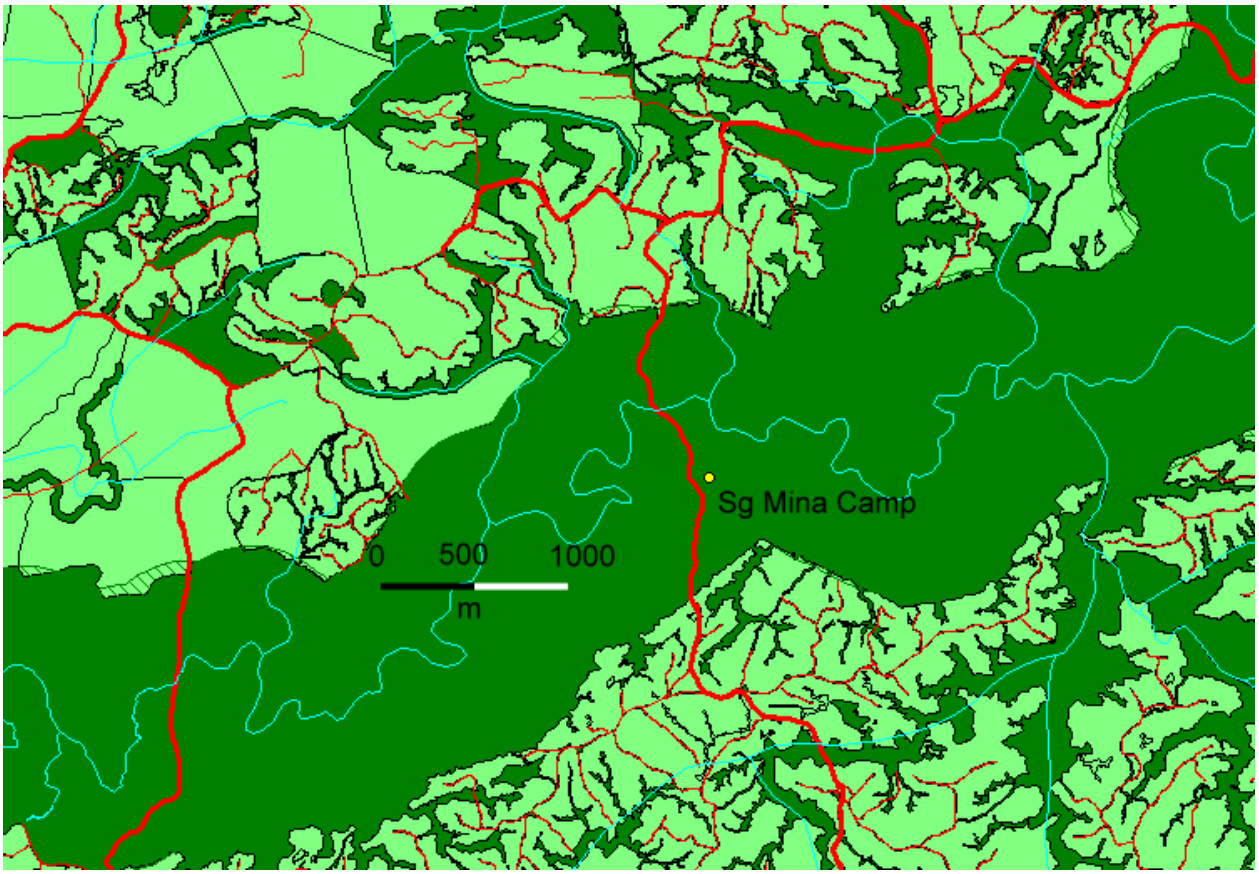


Figure 5.2: Map of the Sungai Mina conservation corridor (dark green), Planted Forest Zone, Sarawak, East Malaysia, showing fragmentation of corridor by the forest road network (red lines).

Features of many roads throughout the PFZ are wide areas devoid of vegetation along the road verges, followed by a transition to forest via dense fern edge vegetation of variable width (Figure 5.3). As a result much of the road corridor width is more similar to a savannah or rocky habitat than to the adjacent moist forest habitat due to an abrupt break in the microclimate (Mader 1984). In order to improve movement of small mammals and other fauna across roads, particularly where they pass through major conservation corridor areas, active or assisted re-forestation of the degraded edge habitat would need to take place.

Figure 5.3: Wide areas devoid of vegetation and bands of dense fern along a forest road bisecting the Sungai Mina conservation corridor, Planted Forest Zone, Sarawak, East Malaysia (Photograph A. Shadbolt 2006).

Fortunately the Planted Forests Project is be well placed to produce planting stock to restore such sites which could be grown at the PFZ's Samarakan Nursery. While such an initiative would require a high-level directive it could also be partially supported and implemented through community participation with the assistance of locally active environmental interest groups such as the Natural Science Society Bintulu (NSSB). The Samarakan Nursery; the main nursery servicing the PFZ (Figure 5.4) has capacity to produce approximately three-million acacia seedlings per month. Conservation staff therefore have an ideal opportunity to arrange for the production of appropriate quantities of local native tree species and develop a strategic programme of ongoing roadside forest restoration throughout the PFZ, provided that native species are able to be propagated using the same methods.

Figure 5.4: Students from the University of Canterbury's NZ School of Forestry inspect a propagation unit at the Samarakan Nursery, Planted Forest Zone, Sarawak, East Malaysia during a field tour in 2005 (Photograph A. Shadbolt, 2005).

Failing an ability or mandate to produce native forest trees for this task at the Samarakan Nursery, an alternative option may be to plant denuded sites with second grade *A. mangium* trees and utilise these as a nurse for native forest restoration. While not an ideal option, elsewhere in the PFZ, and particularly in the Samarakan Conservation Forest, acacia compartments older than seven years provide under-storey conditions similar to the adjacent secondary forest and therefore is likely to provide a nurse crop species that will foster the natural regeneration of appropriate native forest vegetation in the medium to long term. In some recently harvested plantation compartments, mature acacia trees have been retained alongside riparian buffers to bolster their effective width (Figure 5.5); another strategy that should be encouraged throughout the PFZ. Regardless of which option is selected, either scenario is likely to be of benefit to

dispersing animals through the provision of extended cover and reduction of the open area required to be crossed.

Figure 5.5: Acacia *(Acacia mangium)* trees retained during plantation harvest to bolster riparian buffer widths, Planted Forest Zone, Sarawak, East Malaysia (Photograph A. Shadbolt, 2011).

A range of engineering solutions can be implemented to assist wildlife in crossing roads that pass through natural areas, including wildlife overpasses and underpasses. Overpasses may include vegetated land-bridges (Figure 5.6) that provide uninterrupted habitat connectivity between fragmented forest habitats, arboreal canopy bridges for arboreal mammals (Figure 5.7) and strategically located glider poles for gliding fauna. Underpasses may include purpose built dry underpasses, wet culverts and/or appropriately dimensioned pipes. The Compton Road Fauna Structures Array in Brisbane, Australia, incorporates the highest known diversity of fauna friendly structures in any location, and the lessons learned from the construction and monitoring of these solutions (see Veage and Jones 2007) could be used to inform the design and management of roading infrastructure throughout the PFZ.

Figure 5.6: Vegetated land-bridge designed specifically as a wildlife overpass across Compton Road, Brisbane, Australia (Photograph A. Shadbolt 2013).

While it is unlikely that PFZ forest managers will be willing or able to invest in expensive and heavily engineered structures such as vegetated land bridges or purpose built dry culverts, it may be that more simple solutions such as arboreal rope bridges and glider poles could be achieved at relatively low cost and to great benefit to arboreal and gliding species. However such structures are unlikely to aid movement of terrestrial and/or scansorial mammals across roads.

Figure 5.7: Arboreal canopy bridge across Compton Road, Brisbane, Australia (Photograph A. Shadbolt 2013).

However simple solutions that reduce the barrier effect of roads for terrestrial fauna are likely to be more achievable than expensive engineered structures. Such solutions may include the re-vegetation of denuded roadside areas (refer above) and appropriate treatment of existing river and stream crossings. The restoration and appropriate management riparian habitat in the vicinity of, and beneath road bridges, culverts and large diameter pipes, and where required the modification and appropriate management of those structures will capitalise on the presence of the existing built structures. Monitoring use by wildlife of these solutions would in-turn be used to inform their ongoing management, and also to inform future modifications of such structures within the PFZ and elsewhere.

Woody Debris: Fredericksen and Fredericksen (2002) showed that small mammal population densities and species richness was higher in forest areas disturbed by logging and fire in humid tropical forests in Bolivia, and suggest that this may partly have been a result of the higher level of coarse woody debris present in these disturbed forests. Coarse woody debris is also an important structural and functional component in forest ecosystems (Enrong *et al.* 2006) and can also play an important role in animal movement (see Chapter 3) and dispersal.

All species tracked using the spool-and-line method were found to select logs and woody debris as efficient travel routes where step lengths were found to be longer on these substrates than on the ground. Woody debris and logs are likely to be selected for their fast and comparatively silent travel qualities (Bakker 2006; McAdam and Kramer 1998), and for close proximity of protective cover from real or perceived predators (Waldien *et al.* 2006).

Improved connectivity throughout an animal's home range can be provided by long logs, and provision of these logs is thought to positively influence fitness as a result of reduced predation where the animal uses logs as protective cover (McComb 2008). Although levels of coarse woody debris are not reported in this thesis, transect data collected by the primary author in 2010 revealed a significantly lower incidence of this material being present in mature acacia compartments compared with secondary forest in the study area (Shadbolt, unpublished data).

Lower levels of coarse woody debris observed in acacia forests in the PFZ are likely due to intensive pre-clearance harvesting of timber, and post harvest burning to clear the site in preparation for planting (Meijaard and Sheil 2006). As discussed above, this paucity of coarse woody debris may expose animals to increased risk of predation through both lack of cover during movement activity and also through a reliance on more exposed sleeping and nesting sites

that may be more detectable to olfactory predators (Conover 2007). Although acacia stands are shown to be prone to wind damage resulting in tree-fall gaps (Ragai and Tuen 2007), while these fallen trees may be of some use as animal movement substrates, they are unlikely to offer the same degree of cover or nest site opportunities as would larger logs (Lindenmayer *et al.* 2009).

If biodiversity conservation in the PFZ is to be successful in maintaining the current level of species richness across the landscape, key aspects of stand structural complexity like large diameter coarse woody debris needs to be managed in a way that sustains availability of the resource throughout successive harvest rotations. One way of achieving this is ensuring the retention of large trees in forest and plantation compartments. These trees are not only important for the provision of snags, tree cavities and subsequent large diameter woody debris, but they are also fundamental for the provision of hollow logs which can only result from standing hollow trees (McComb 2008).

An alternative management solution to the paucity of large diameter deadwood in secondary forest, and especially plantation compartments, could be the provision of artificial nest boxes to provide sleeping and/or nursery nest site opportunities for cavity nesting species like *T. picta.* Lindenmayer *et al.* (2009) show that for arboreal marsupials, experimentally placed nest boxes had a high occupancy rate (58.3%) in young forest in Victoria, Australia that had a paucity of natural tree hollows compared to older forest where the occupancy rate was as low as (4.1%). However they suggest that the provision of artificial nest boxes needs to be weighed against other strategies for ensuring the provision of tree hollows such as retention and perpetuation of mature trees, or the stimulation of cavities in trees through either intentional wounding and/or inoculation with fungi. Given that the scale of plantation establishment in the PFZ is likely to necessitate the conversion to, and harvesting of, approximately 60 hectares of acacia per day, it is

unlikely that the provision of artificial nest boxes across such a broad landscape mosaic would be achievable, affordable or indeed a desirable solution. Therefore other means of retaining the existing natural nest site opportunities needs to be investigated further.

Painted Treeshrew: Treeshrews have been found to vary widely in their tolerance to forest disturbance and conversion to plantation forestry (Emmons 2000; Munshi-South *et al.* 2007; Munshi-South 2005). However prior to this study little was known of the ecology of *T. picta* other than it is diurnal (Payne and Francis 2005) and that it is best adapted to old growth and secondary forests, and also survived in forest remnants within maturing tree plantations (Han and Stuebing 2008). In this study, *T. picta* was found to use both secondary forest and acacia plantation compartments. Although acacia plantation compartments were less complex in terms of forest structure, floral diversity and coarse woody debris, radio-tracking revealed that *T. picta* were able to cover impressive distances within relatively short timeframes and reside within this vegetation type for extended periods. However while *T. picta* were observed to use mature acacia forest, it still remains unknown whether the species will enter young acacia compartments.

Although based on the limited replications of this study, painted treeshrews tracked by radio telemetry were found to occupy large home ranges for their size, similar to other Tupaiids studied by Emmons (2000). Where forest roads occurred in the vicinity of an animals' home range, these features were found to regulate the shape of the home range, with no animal location points being recorded on the opposite sides of roads, thus reinforcing the barrier effects of these anthropogenic features that was also demonstrated on a finer scale by spool- and-line tracking.

Painted treeshrews were shown to be opportunistic rather than obligate users of both tree cavities and hollow logs for nest sites, and the presence of large diameter dead wood in forest fragments

and acacia plantation compartments is likely to critical to the long term persistence of this species across the PFZ landscape. The likely competition from other Tupaiids (see Emmons 2000) and squirrels for suitable nest sites further reinforces the need to manage the large diameter tree and deadwood resources sustainably in order that potentially vulnerable species; as common as they may be at present, are maintained at viable population levels across the landscape and throughout the working life of the plantation.

Regarding squirrels, an interesting but unexpected observation was evidence of inter-specific next sharing with the possible *T. picta* mimic (See Banks 1931), the three-striped ground squirrel *(Lariscus insignis).* This incidence, recorded by camera trapping, is certainly worthy of further research and investigation, as to-date it is still unknown as to whether treeshrews build their own nests, or whether they may use the nests of squirrels. Furthermore this is the first recorded incidence of inter-specific nest sharing in Tupaiids, and it is possible that there may be other inter-specific associations between the two species still to be discovered.

5.2 The Future

Meijaard and Sheil (2008) reinforce that in order to successfully sustain biodiversity in heavily managed landscapes such as those of fast-growing timber plantations, good management practices are required, incorporating the current pool of scientific knowledge relating to species vulnerability into forest management interventions. This is also reinforced in the requirements of the Malaysian Criteria and Indicators for Forest Management Certification of Forest Plantations (MC&I [Forest Plantations]) (Refer Chapter 1).

Under this certification scheme forest managers are required to conduct monitoring appropriate to the scale and intensity of the Forest Management Unit (FMU), and incorporate the findings into revisions of the Forest Management Plan (FMP). Unfortunately the current pool of knowledge is far from complete in tropical forest environments, and even less so for plantation landscapes in this region; a situation not helped by the difficulty of obtaining research funding for projects associated with plantations, and subsequent difficulty of publishing the results of plantation-related wildlife research in scientific journals. However as discussed earlier in this chapter, in the absence of more robust scientific data, even observational data has an important role to play in informing the precautionary approach to plantation landscape management, particularly when obtaining more robust data is not likely to be achievable in the short to medium term without a significant funding base.

In this context, the findings of studies like those reported here, and the range of related studies, both published and un-published, and regardless of whether they are experimental or largely observational, need to be incorporated into forest management plans and policies to inform and steer the two closely related fields of plantation development and wildlife management. However regardless of policy, the key to ensuring such initiatives are executed on the ground is likely to rely on the transfer of knowledge, along with an appreciation of the value of both wildlife and their habitat requirements, to plantation staff across all levels of the organisation from senior managers through to the machinery operators, planters and harvesting crews. To date Grand Perfect Sdn. Bhd. has excelled in this aspect of staff education and training, facilitated largely by a strong induction training programme for plantation workers and interns from Sarawak Forestry Department. These education programmes are also an important and measurable condition of achieving certification under the MC&I (Forest Plantations).

It is obvious from the trap-catch indices observed across successive years in the Samarakan Conservation Forest that a single inventory of a given site is unlikely to yield an accurate picture of the true value of the site for the conservation of biodiversity. Moreover, repeated sampling at selected sites across the PFZ is required in order to provide a more accurate assessment of the real value of the range of patch sizes for non-volant small mammals and estimate probability of detection. To this end, further trapping inventories using standardised sampling protocols across a range of patch sizes is recommended in order to corroborate the findings of this research.

Nielsen *et al.* (2009) re-emphasise the critical need for monitoring programmes that inform conservation efforts based on changes or trends in a species' status, and that such monitoring programmes should be taxonomically broad and target both rare and common species alike. In terms of such monitoring, Stuebing (2007) describes the challenge for biodiversity conservation in the PFZ as that of being able to maintain long term records that can suggest which management path should be taken for each particular species or biological community. Species populations with negative long-term growth rates will require constant management to prevent their extinction (Holsinger 2000), and management regimes need to be adaptive (adaptive management; Walters 1986) as more is revealed of the habits of wildlife occupying such heavily modified systems.

To this end, the inclusion of common species such as *T. picta* and *M. rajah* in monitoring programs is important in ensuring that population trends for these species are detected at an early stage. If a negative population trend should be identified at an early stage, mitigation can be implemented in a timely manner, and hopefully well before the species has declined to a status that is no longer described as common.

Notwithstanding some of the concerns discussed in this thesis, if well managed the future of non-volant small mammals in the PFZ looks promising. However the persistence of this faunal group is likely to rely on maintaining the an optimal spatial distribution of natural forest areas throughout the landscape mosaic, and ensuring that the internal landscape of both the patch and acacia matrix contain the necessary fine scale elements such as decay cavities and large woody debris.

With continued support, and appropriate management of the Planted Forest Zones conservation estate, the Planted Forests Project of Sarawak is set to provide an exemplar for biodiversity conservation in tropical production landscapes. Being listed as one of the six most important scientific experiments in the world (Barone 2007), the eyes of the world are upon Sarawak, and with the continued support of the State, local communities, dedicated conservation staff and both national and international collaborators, the success of the project is certainly achievable.

5.3 Research Needs

As wildlife conservation efforts in the PFZ are in their infancy, future research needs for small mammals are numerous. Here I suggest and discuss four potential ongoing research projects that could be carried out in the PFZ: 1) ongoing behavioural research related to response to habitat fragmentation, 2) ongoing autecological studies of the painted treeshrew, 3) temporal assessment of the utility of small forest patches embedded within an acacia matrix to support non-volant small mammal populations, and 4) a 'lifeboat' study of the ability of small non-volant mammals to seek remnant forest patches as refuges during plantation harvesting.

Ongoing Behavioural Research: The research reported in this thesis has provided a number of interesting observations and conclusions. However as recommended in the respective chapters, more information is needed where sample sizes for species have been small. Furthermore most species studied did not have large control samples (i.e. animals released and tracked using the spool-and-line method within their own home ranges). Therefore future controlled field research that adds to the pool of behavioural data relating to non-volant small mammal movement and response to habitat edge will make an important contribution to our understanding of small mammal use of, and likely persistence in modified habitats like those of the PFZ.

Comparatively few individuals were recorded entering the acacia matrix, and when they did so it tended to be either for short, possibly exploratory excursions, or near the end of the thread path. As a result spool-and-line data on movement behaviour within acacia was very limited. However obtaining movement data for individuals translocated to and released within acacia compartments would provide an informative comparison between movement and behaviour in home territories, novel patches and acacia compartments. Questions to be investigated could include: is the movement of individuals influenced by the orientation of plantation rows? Is movement less tortuous and more directional in acacia than in the other environments? Are individuals more likely to cross from acacia compartments into native forest than from native forest to acacia? Do experimentally placed logs within acacia compartments increase movement distance from point of release compared to control sites with no logs? Answers to these research questions could provide greater insight into the responses of small mammals to broad-scale landscape change, and help inform plantation establishment and management practices.

While the spool-and-line method has proven to be effective in detecting behavioural responses to a range of edge features on small spatial and temporal scales, investigating dispersal across

larger scales using radio telemetry provides an important next step in this investigation. Chapter 4 illustrated the insights that even a very coarse radio telemetry study can reveal, where a small number of recorded locations demonstrated the dispersal ability of *T. picta* in a short period of time after being translocated to a novel forest patch. With an increased frequency of fixes, as carried out at the Kakus Nursery Forest (KNF) area in Chapter 4, and with tracking over a longer time period, researchers could gain a very clear picture of an individuals' exploration of unfamiliar environments, response to edge, excursions through the matrix, and response to management interventions such as reduction of road crossing widths or use of any road crossing structures.

Painted Treeshrew: Much is still to be learned about the biology and behaviour of *T. picta* in both its natural habitat and plantation landscapes like the PFZ. As a result there are many research opportunities associated with this species over and above investigations into its response to habitat fragmentation and forest conversion. These include the species breeding biology, diet, home range and social behaviour. From the findings of this present study, of special interest is the nesting behaviour of the species; in particular the suggestion of inter-specific nest sharing with *L. insignis*. Painted treeshrew nest site location using radio telemetry and/or spool-and-line tracking is therefore recommended, along with the continuation of camera trapping at nest sites to gather supporting evidence for the theory.

Such a study would necessitate the capture and radio collaring of individuals of both *T. picta* and *L. insignis*. While it would be desirable that daily activity patterns of both species were recorded as was done for *T. picta* at the KNF site, for the purposes of this study, and given the likely limitations on field staff, emphasis should be placed on fine-scale nest site location for both

species. However continuous tracking has the advantage of potentially being able to reveal other inter-specific relationships over-and-above possible inter-specific nest sharing.

As individual nest sites for individuals are likely to be finite, nest site location would continue until an accumulation curve asymptote is reached, and camera traps should be set at each nest site. Ideally two cameras shall be set at each nest site. One camera should be set to record still photographs, while the second would record a short video segment. Depending on the camera make and model, the cameras set to record video can be programmed to record only at the times that individuals are expected to be arriving at or leaving the nest sites (i.e. generally an hour either side of dusk and dawn) in order to conserve battery life and reduce the number of return visits by field staff. However a pilot study is recommended where the cameras are operational 24 hours each day to ensure *T. picta* and/or *L. insignis* activity is not occurring at other times of the day. This is particularly important where the nest is a natal nest.

Having two cameras operational at each nest site throughout the duration of the study helps safeguard against lost data in the event that one camera malfunctions, is knocked out of alignment, its field of view is obscured or is otherwise damaged. Furthermore, having one camera set to record video can provide useful information on nest building and/or maintenance activity by individuals.

Two important factors to consider when selecting a camera trap model for use with small mammals are its sensitivity and its response time. Many models of camera trap are designed to detect movement and capture images of larger animals, and are often not sensitive enough to detect smaller animals. Furthermore, the response/start-up time of many cameras is too slow to photograph small, fast moving mammals. As a result images are often captured after the target

animal has exited the cameras field of view, or from experience, identification of the species must rely on the characteristics of the animals' tail as it exists' the scene. Therefore the response time is particularly important when the camera is placed very near to the target area; an important requirement for the accurate identification of small mammals.

It is hoped that from this observational study robust evidence supporting the hypothesis for an inter-specific relationship between *T. picta* and *L. insignis* could be provided. However in order to eliminate other tupaiid associations with *L. insignis*, other predominantly terrestrial treeshrew species (i.e. *T. longipes* and *T. tana*) should also be trapped, fitted with radio collars and have their nest sites monitored with camera traps using the same protocols. By doing so the study would have a controlled experimental element to its design beyond that of a purely observational study.

Small Patch Monitoring: Small patches of remnant forest are intended to be retained within all acacia plantation compartments across the broad PFZ landscape to function as lifeboats for both faunal and floral biodiversity. It is assumed that these small patches will provide a safe refuge for mobile species during initial forest clearance for plantation establishment, and also during successive plantation harvest operations. Furthermore it is assumed that the small patches will be able to support small but temporarily isolated populations of a range of species until such time that the new plantation matures to a stage where individuals are able to disperse from the patch into the acacia, and/or move through the acacia compartments in search of neighbouring patches. In the case of species like *T. picta* that are perhaps less sensitive to habitat modification, these species may be able to utilise the acacia itself either as core habitat or as a resource extension to the core habitat provided by the original patch.

However while this model seems plausible in theory, small mammal trapping inventories in forest patches embedded within the acacia have revealed comparatively low species diversity and abundance, and a complete absence of many species that have been recorded in larger forest blocks. Unfortunately all small mammal inventories carried out to date within these small patches in the PFZ have been conducted where the surrounding acacia matrix is either at mid or near the end of its rotation age. Hence any species that found themselves in the patch and subsequently isolated during the initial plantation establishment phase may have already dispersed from the patch, or worse, succumbed to other adverse phenomenon. Such phenomena could include predation, food and/or other resource scarcity, or mortality due to other causes, and in the absence of a suitable mate, failed to breed and produce viable offspring.

Therefore forest managers have not yet been able to ascertain whether or not the forest patches are functioning in the way they were intended as lifeboats for biodiversity, or conversely whether they have been relatively vacant patches since the time of their isolation as a result of being too small to maintain viable populations even in the short term. For example during the trapping session in the Kapur-1 (1.0 ha) forest patch in 2010, despite an extensive trapping effort and thorough patch coverage just a single *M. rajah* was captured in the patch, indicating that although the patch was indeed occupied by the species, the population was likely to be functionally extinct.

Here I propose a long-term small mammal monitoring programme that will shed light on the population dynamics of small mammals in these small remnant patches, and provide evidence for or against their actual utility as lifeboats for biodiversity. Note however that this proposal is specifically targeted at an assessment small-mammalian biodiversity, and it is assumed that other

biodiversity monitoring programmes would occur concurrently if and where appropriate in the same monitored patches.

In terms of methodologies, small mammal trapping would be carried out in randomly selected small forest patches that are isolated within mature acacia forest that is nearing the end of its rotation and therefore due for harvest. Ideally a range of patch sizes would be surveyed, however limited funding and resources is likely to mean that compromises will need to be made to the scale and scope of any such study unless significant external funding can be secured to cover the duration of such a study.

Depending on funding, a series of six trapping sessions would be carried out in each forest patch: 1) immediately prior (within two months) of harvest; 2) immediately following (within one month) of harvest/patch isolation; 3) six months from harvest; 4) 18 months from harvest; 5) three years from harvest, and 6) when the re-planted crop trees have reached an age of approximately four years at which stage it is anticipated that animals will be able to again disperse through the matrix.

During the first two inventory sessions, trapping would also be carried out concurrently in paired forest patches that were not subject to plantation harvesting to provide a control sample. These control patches will enable researchers to separate any changes in population diversity and abundance as a result of plantation harvest from natural background population fluctuations. Unfortunately paired control patch inventories cannot be practically achieved through all six of the inventory sessions due to the rapid pace of plantation harvest (up to 66 ha per day) and the need to harvest acacia blocks on a seven year rotation. However even controlling only the first

two inventories will still enable a robust assessment of the immediate effects of harvesting on population dynamics between the experimental and control patches.

Lifeboat Study: Another dimension to the above study would be the use of radio telemetry to determine the ability of individuals of a range of species residing within acacia prior to harvest to locate and move to remnant forest patches during plantation harvesting activities. This is likely to be an important investigation that will provide evidence either for or against the ability of these remnant patches to function in the way they were envisaged; i.e. as virtual lifeboats for biodiversity.

To investigate this, small mammals would be trapped within acacia plantation compartments surrounding small permanent patches of native forest that are to be retained and protected throughout successive plantation rotations, fitted with radio collars and released again at their points of capture. Locations of the radio-collared individuals would be determined at twenty minute intervals during their active periods for a period of (minimum) three days (Refer to methods discussed in Chapter 4) prior to any harvesting related activities (including road construction) beginning in the area. By conducting this first stage, researchers will be able to obtain valuable home range and habitat use data for species residing in acacia to compare with data collected by others for those species residing in natural forest. For *Tupaia picta*, this data can be used to compare and contrast with the findings contained in this thesis for individuals occupying remnant forest patches, and also for those released into novel patches.

Following the initial pre-harvest radio tracking, continuous radio tracking would continue throughout the duration of the harvesting activities, and until such time that either a) the signal of the transmitter is lost and cannot be re-located, b) the animal locates and remains within a forest

patch for three consecutive days, or c) the dead animal and transmitter is retrieved. While the pre-harvesting radio tracking will provide one level of control against which to compare animal movement behaviour during harvest, a control group should ideally be established in an acacia compartment which is not subject to immediate harvesting. Here tracking would follow the exact same protocols as the experimental group, and would continue for the same duration as this group. The control compartments would also need to contain a small remnant forest patch(s) in order to provide as near as possible the same physical landscape as the experimental compartments.

Prior to all harvesting activities, the Sarawak Planted Forests GIS department produce detailed harvesting maps for each compartment and block. These harvesting maps include geographic data such as the physical topography, any vegetation to be retained/protected, waterways, existing and proposed roading systems, and also the accurate locations of all harvesting machinery, cable-yarding haul lines and log landing points. These mapped features will provide important reference points for tracked animal movements, and it may also be possible to fit GPS data loggers to mobile machinery such (e.g. excavators and bulldozers) to compare their relative locations with animal movement behaviour.

Concluding Remarks

The Planted Forest Project offers timely opportunity to conduct monitoring and research that can help direct the way in which future plantation forestry is established and managed in Sarawak and further afield. Regarded as one of the six most important scientific experiments in the world by Discover Magazine in 2007, ongoing research such as that presented in the preceding chapters of this thesis, and also the potential research ideas presented in this chapter play an important

role in maintaining the high profile of this project amongst both the scientific community and wider international public.

Given how little is known about the ecology and behaviour of small mammals occupying not just plantation forest landscapes, but even natural forest environments on Borneo, any and all information gleaned from both experimental and observational studies is valuable. I believe that the findings of this thesis have indeed been valuable, and have provided a significant contribution to the current body of knowledge on these species, and has highlighted a number of gaps in knowledge that are worthy of further research of both experimental and observational nature.

While replicated experimental approaches will always be the preferred approach to autecological research, in developing States such as Sarawak where funding and support for long term research projects cannot be guaranteed, observational data may be one of the only sources data available for some species or phenomenon on which to base management decisions. Unfortunately this situation is likely to remain the case until such time that funding is secured for long-term, large scale and scientifically robust investigations into the observations and findings highlighted in this thesis. With ongoing support, the Planted Forests Project could offer the perfect opportunity to lead the way in biodiversity research in managed landscapes, and in doing so provide an exemplar of multi-value plantation management for Borneo and wider Tropical East Asia.

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APPENDIX 1

A Brief Introduction to Selected Non-volant Small Mammals of the Planted Forest Zone, Sarawak, East Malaysia

This appendix briefly describes some of the more common of the non-volant (non flying) mammals that are discussed in depth in later chapters in terms of their presence, abundance and particular behaviours in the Planted Forest Zone (PFZ) of Sarawak, East Malaysia. Here each of the species are described in terms of their classification, common names and diagnostic features including weight and measurement ranges, IUCN status and population trends. Distribution, ecology and habitat requirements are also discussed, along with any specific threats the species may be faced with. Species described here include the long footed treeshrew (Tupaia longipes), painted treeshrew (T. picta), large treeshrew (T. tana), three-striped ground squirrel (Lariscus insignis), brown spiny rat (Maxomys rajah), Muller's rat (Sundamys muelleri) and the long tailed giant rat (Leopoldamys sabanus).

Photo: Brown spiny rat *(Maxomys rajah)* trapped in a forest remnant in the Planted Forest Zone (PFZ), Sarawak, East Malaysia (Photograph A. Shadbolt 2009).

APPENDIX 1

Tupaia longipes *(Thomas 1893)*

Common Name	Long Footed Treeshrew
Order:	Scandentia
Family:	Tupaiidae
Weight:	156 – 270 g
Head-body Length:	170 – 235 mm
Tail Length:	170 – 242 mm
Hind Foot Length:	45 – 56 mm
IUCN Status:	Least Concern
Population Trend:	Decreasing

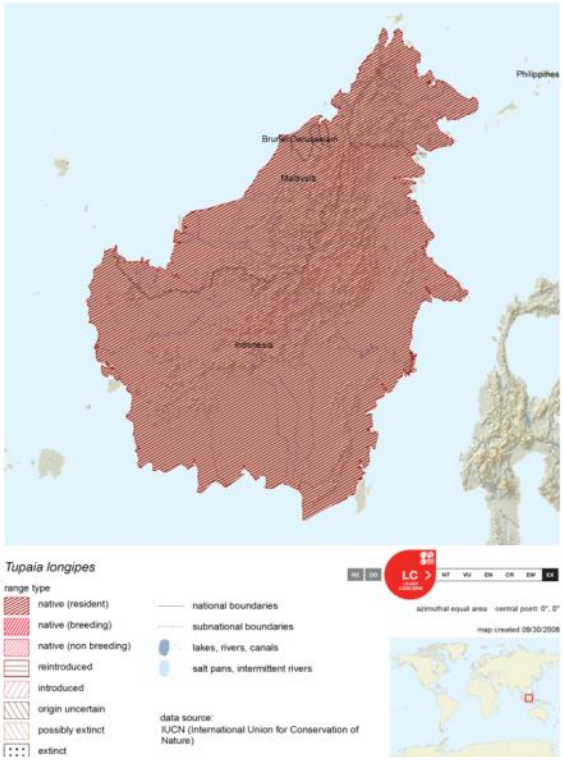

Figure 1: Likely range of the long footed treeshrew *(Tupaia longipes)*. Source IUCN Red List.

Distribution: Endemic to Borneo. Likely to occur throughout the lowlands and hills up to 1100 m above sea level in the Kelabit uplands (Payne and Francis 2005). Refer Figure 1

Ecology and Habitat: Diurnal, occurring in forests and also in gardens and plantations where they occur adjacent to forests. Often active on the ground or on or around fallen woody debris (Figure 2) and low woody vegetation where it feeds on invertebrates and sweet or oily fruits (Payne and Francis 2005).

Threats: Likely to have experienced declines as a result of forest loss at low elevations. Main threats are therefore deforestation and habitat degradation as a result of agricultural development and conversion of forest to non-timber plantations (Han and Stuebing 2008a).

Figure 2: Long footed treeshrew *(Tupaia longipes)*. (Photograph A. Shadbolt 2009).

APPENDIX 1

Tupaia picta *(Thomas 1892)*

Common Name:	Painted Treeshrew
Order:	Scandentia
Family:	Tupaiidae
Weight:	55 – 179 g
Head-body Length:	168 – 240 mm
Tail Length:	140 – 170 mm
Hind Foot Length:	40 – 46 mm
IUCN Status:	Least Concern
Population Trend:	Decreasing

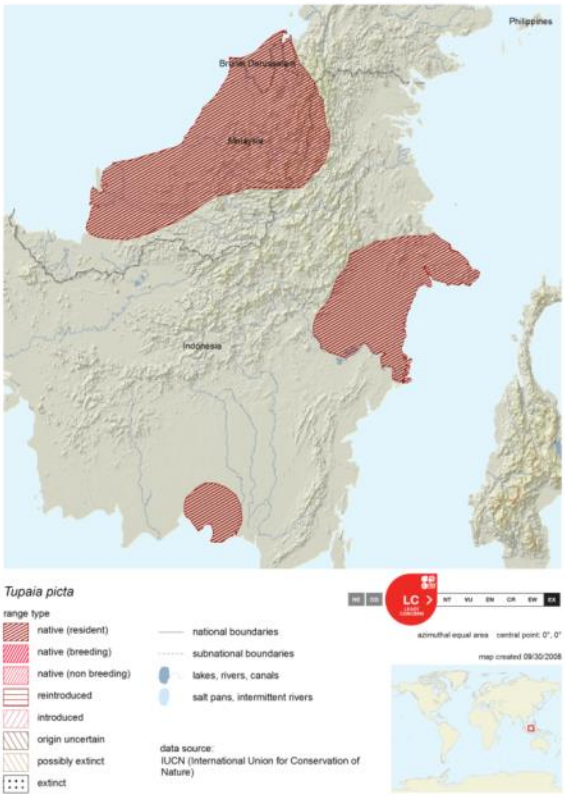

Figure 3: Range of the painted treeshrew *(Tupaia picta)*. Source IUCN Red List.

Distribution: Endemic to Borneo. Recorded from the north-west between Balingain on the Sarawak coast to Tasek Merimbun in Brunei and including the areas of Usun Apau, Gunung Batu Song, Kelabit uplands and Gunung Mulu. A sub-species, *T. picta fuscior* is known from just three locations in near the coast of East Kalimantan between Samarinda and Labuhan Kelambu (Payne and Francis 2005).

Ecology and Habitat: Diurnal. Otherwise unknown (Payne and Feancis 2005). Survives in old growth and secondary forests and shows some adaptability to disturbed habitats as evidenced by its occurrence in forest remnants within >5 year old tree plantations (Han and Stuebing 2008b).

Threats: Likely to going through population declines as a result of habitat loss related to logging and other resource use.

Figure 4: Painted treeshrew *(Tupaia picta)*. (Photograph A. Shadbolt 2006).

APPENDIX 1

Tupaia tana *(Raffles 1821)*

Common Name:	Large Treeshrew
Order:	Scandentia
Family:	Tupaiidae
Weight:	154 – 305 g
Head-body Length:	165 – 301 mm
Tail Length:	140 – 162 mm
Hind Foot Length:	40 – 46 mm
IUCN Status:	Least Concern
Population Trend:	Decreasing

Figure 5: Range of the large treeshrew *(Tupaia tana)*. Source IUCN Red List.

Distribution: Sumatra and adjacent small islands. **Borneo:** Likely to occur throughout Borneo the lowlands and hills up to 1000 m above sea level, although has been recorded at elevations up to 1500 m (Payne and Francis 2005). Appears to be absent from south coast of Borneo (Han and Stuebing 2008c) (Figure 6).

Ecology and Habitat: Diurnal and mainly terrestrial occurring in both tall and secondary forests (Payne and Francis 2005) and also fruit orchards (Han and Stuebing 2008c).

Threats: Deforestation remains a threat to this species.

Figure 6: Large treeshrew (Tupaia tana). (Photograph A. Shadbolt, 2010)

APPENDIX 1

Lariscus insignis *(F. Cuvier 1821)*

Common Name: 3-Striped Ground Squirrel

Order: Rodentia

Family: Sciuridae

Weight: 195 g

Head-body Length: 170 – 230 mm

Tail Length: 122 – 138 mm

Hind Foot Length: 33 – 46 mm

IUCN Status: Least Concern

Population Trend: Decreasing

Distribution: Peninsula Malaysia, Sumatra, Java and adjacent small islands. **Borneo:** Occurs in scattered lowland sites in most areas throughout Borneo except for Sabah and the northern parts of East Kalimantan (Payne and Francis 2005) (Figure 9).

Figure 7: Range of the three-striped ground squirrel *(Lariscus insignis)*. Source IUCN Red List.

Ecology and Habitat: Diurnal and terrestrial occurring in both tall and secondary forests where its diet consists of fruit and insects (Payne and Francis 2005). Has been recorded up to 1500 m (Hedges *et al.* 2008).

Threats: No apparent major threats to this species (Hedges *et al.* 2008).

Figure 8: Three-striped ground squirrel *(Lariscus insignis)* (Photograph A. Shadbolt 2010)

APPENDIX 1

Maxomys rajah *(Thomas 1894)*

Common Name:	Brown Spiny Rat.
Order:	Rodentia
Family:	Muridae
Weight:	92 – 218 g
Head-body Length:	139 –218 mm
Tail Length:	162 – 210 mm
Hind Foot Length:	35 – 43 mm
IUCN Status:	Vulnerable
Population Trend:	Decreasing

Distribution: Peninsula Malaysia, Peninsula Thailand, Sumatra and adjacent islands. **Borneo:** Recorded from many locations in the coastal regions of Sabah and Sarawak and also from Kutai in East Kalimantan and Riam in Central Kalimantan (Payne and Francis 2005) (Figure 12).

Figure 9: Range of the brown spiny rat *(Maxomys rajah)*. Source IUCN Red List.

Ecology and Habitat: Nocturnal and mostly terrestrial, occurring in tall and secondary forests (Payne and Francis 2005), but not present outside forests (Aplin *et al.* 2008).

Threats: Habitat loss due to commercial logging and conversion of forest habitat to agricultural land uses. As a result, populations of this species are estimated to have declined by more than 30% over the last decade, resulting in a change to its 1996 IUCN status of *'Least Concern'* to its present vulnerable status (Aplin *et al.* 2008).

Figure 10: Brown spiny rat *(Maxomys rajah)* (Photograph A. Shadbolt 2008).

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Sundamys muelleri *(Thomas 1894)*

Common Name:	Muller's Rat.
Order:	Rodentia
Family:	Muridae
Weight:	160 – 305 g
Head-body Length:	179 – 244 mm
Tail Length:	191 – 277 mm
Hind Foot Length:	37 – 49 mm
IUCN Status:	Least Concern
Population Trend:	Decreasing

Figure 11: Range of Muller's rat *(Sundamys muelleri)*. Source IUCN Red List.

Distribution: Peninsula Malaysia, Peninsula Thailand, Peninsula Burma Sumatra and adjacent islands, and Palawan. **Borneo:** Recorded from the lowlands throughout Borneo and to 1130 m in the Kelabit uplands (Payne and Francis 2005), and to 1650 m on Mt Kinabalu, Sabah (Ruedas *et al.* 2008) (Figure 15).

Ecology and Habitat: Nocturnal, mostly terrestrial and often found near streams and moist habitats in forested and lightly wooded areas where it feeds on both plant and animal matter (Payne and Francis 2005; Ruedas *et al.* 2008),

Threats: Unlikely to be affected by habitat loss, however is likely to be hunted in non-Muslim areas.

Figure 12: Muller's rat *(Sundamys muelleri)* (Photograph A. Shadbolt 2007).

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Leopoldamys sabanus *(Thomas 1887)*

Common Name:	Long-tailed Giant Rat
Order:	Rodentia
Family:	Muridae
Weight:	250 – 532 g
Head-body Length:	215 – 273 mm
Tail Length:	327 – 402 mm
Hind Foot Length:	40 – 52 mm
IUCN Status:	Least Concern
Population Trend:	Stable

Distribution: South-east Asia, Sumatra, Java and adjacent islands. **Borneo:** Recorded throughout lowland and hills of Borneo, and to as high as 3100 m on Mt Kinabalu, Sabah. (Payne and Francis 2005) (Figure 18).

Figure 13: Range of the long-tailed giant rat *(Leopoldamys sabanus)*. Source IUCN Red List.

Ecology and Habitat: Nocturnal. Occurs in tall and secondary forest habitats where it forages both within the canopy and at ground level (Payne and Francis 2005; Lunde *et al.* 2008). The animal's diet consists of insects, fruit, and other vegetable matter (Lunde *et al.* 2008).

Figure 14: Long-tailed giant rat *(Leopoldamys sabanus)* (Photograph A. Shadbolt 2007).

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APPENDIX 2

A Parachuting Treeshrew? The Curious Case of the Lesser Treeshrew *(Tupaia minor)*

Antony B. Shadbolt
University of Canterbury, NZ School of Forestry
Email: antony.shadbolt@ccc.govt.nz

Short Communication

Hildebrand (1995) reports that several small squirrel species have adapted the behavioural response of parachuting to retard falling and evade predators by spreading their legs and tail, and falling flat to the airstream. During a visit to the Fairy Caves; a popular tourist attraction near the small town of Bau, Sarawak, I had the fortune to witness a similar but previously unrecorded parachuting behaviour in an arboreal treeshrew, the lesser treeshrew *(Tupaia minor)* (Figure 1).

Figure 15: Lesser treeshrew *(Tupaia minor)*. (Source Payne and Francis 2005)

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The Fairy Caves (N 0401803, E 0152728) and surrounding dipterocarp forest remnant of approximately 116 ha in area are managed and administered by the Sarawak Forest Department as a Nature Reserve; a reserve category that is a relatively new addition to The State's protected area network. The Fairy Caves and Nearby Wind Caves Nature Reserves are identified as being important for many plant and invertebrate species that are endemic to the respective limestone hills (Hazebroek and Morshidi 2001).

Both the Fairy Caves and Wind Caves are tourist attractions that have proven popular with local Sarawakians and visitors to The State alike. As a result of the popularity of the area with tourists and locals, some local wildlife species appear to have habituated to the regular human presence at the site, and even secretive species like treeshrews (Emmons 2005) are able to be viewed at relatively close proximity; possibly the result of either intentional and/or accidental provision of food by human visitors.

The main entrance to the Fairy Caves is located at the top of a tall concrete staircase (Figure 2) constructed at the base of tall limestone cliffs just inside the edge of the forest. On 12th June 2011, at 1715 hrs, I encountered an individual of the species *T. minor* at a distance of less than two metres on the outside of the safety balustrade on the uppermost platform of the staircase. Cornered and with no clear route of escape, the treeshrew jumped downwards and outward from the platform.

Figure 16: Tall concrete staircase leading to Fairy Cave entrance, Bau Sarawak. (Photograph A. Shadbolt 2011)

With a perfect birds-eye-view of the animals fall, I observed that as it descended it extended both its' fore and hind limbs outward, and flattened out the hairs on its tail resulting in a flat ventral surface area that was exposed to the airstream. This response effectively retarded the animals fall, and although both the fore and hind limbs flailed in the air throughout the decent, the tail remained flattened and by subtly altering the tails angle and trim it was able to achieve subtle changes in trajectory during its controlled fall. Upon landing on the forest floor more than ten metres from the base of the staircase structure (Figure 3), the individual moved off at speed through the undergrowth apparently unharmed by the event.

Figure 17: View from top of Fairy Cave staircase to forest floor below (Photograph A. Shadbolt 2011).

By measuring the height of individual step risers and multiplying by the number of risers between the forest floor and the uppermost platform from where the animal launched itself, I determined the distance of the retarded fall to be approximately 24.00 m in height. The horizontal displacement between launching and landing locations was estimated to be between ten and 12.00 m, resulting in a controlled parachute descent between 67.40^{o} and 63.50^{o} respectively from the horizontal.

APPENDIX 2

Discussion

Lesser treeshrews are the smallest of the genus Tupaia (Lyon 1913), and are described s being mainly arboreal, often seen at heights of 3 – 8 m above ground and sometimes to 20 m on lianas, branches and small trees (Payne and Francis 2005). Similarly Wells (2005) also recorded a large proportion of *T. minor* activity taking place in the canopy above ten metres, and therefore it comes as no surprise that the individual was observed at this height on the stairway.

Because the descent path was calculated to be steeper than 45^{o} from the horizontal, and the animal only appeared to have minimal control over its trajectory, the animal was described to parachute rather than glide. The behaviour observed in *T. minor* exhibits many of the hallmarks of other parachute and gliding fauna as listed by Hildebrand (1995). These behaviours include the fact that 1) all parachutists are arboreal, 2) they extend their limbs out to the side, 3) they control their primary orientation (see Fraenkel and Gunn 1961) so that their flattened ventral surfaces are exposed to the airstream, and 4) may have specialised, flattened tails.

All arboreal treeshrews have tails that are considerably longer than their head-body length compared to the more terrestrial and/or scansorial treeshrews whose tails are shorter Kloss (1911). This trait is likely to be an adaptation suited to arboreal life where the elongated tail may function as a counter-balance; an adaptation observed in many arboreal species (Hildebrand 1995) including clouded leopard *(Neofelis nebulosa)* (Sabah Forestry Department 2004). While a lengthened tail would provide such balancing assistance, it would also effectively increase the surface area exposed to the airflow during a controlled fall, and it is therefore possible that the lengthened tail fulfils at least two functions associated with arboreal life. Interestingly Hose (1893) noted that the hairs on the tail of *T. minor* were rather

short compared to other treeshrews, and it would therefore be interesting to investigate whether these short hairs may translate to a degree of rigidity and resistance against the airstream during a fall compared to longer less rigid hairs.

Emmons (2005) observed that while *T. minor* did not seem to exhibit strong anxious reactions to people below them, when threatened from above they were greatly alarmed (Emmons pers. coms)[1], and their typical response was to drop immediately to the ground; a similar response to that of the ruddy treeshrew (*T. ferruginea)* as reported by Ridley (1895). Emmons (2005) also observed that when feeding or resting, *T. minor* were often observed to carry out these activities in bowers screened by leaves from above. Therefore aerial predation is likely to present a significant threat to this arboreal species, and it is probable that parachuting from the canopy has evolved as a mechanism for predator avoidance and escape.

In this sense, it is suggested that parachuting from the forest canopy as a means of predator avoidance could represent the origins of gliding in mammals. Although this short communication is based on a single observation of the behaviour only, such observations are important to disseminate, otherwise such behaviour would largely go unreported and/or remain purely anecdotal. Further reporting of the phenomena would lend more weight to the argument. While further field observations of this unique behaviour would be difficult to achieve under completely natural conditions, sites like the Fairy Caves and Wind Caves Nature Reserves where animals have habituated to regular human presence may provide ideal sites for ongoing observation and research into this curious phenomenon.

[1] Email Communication: Louise Emmons, 7th July 2011.

APPENDIX 2

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APPENDIX 3

Photographic Acknowledgements

Roslina Ragai

APPENDIX 3

Azizan Juhin

APPENDIX 3

Kelvin

Kenny Jones

APPENDIX 3

Leigh and Damu

Beldin Giman

APPENDIX 3

Joanes Unggang

APPENDIX 3

Jimi Teo

APPENDIX 3

Nyegang Megem

APPENDIX 3

Steven Stone

APPENDIX 3

Alex Jukie

APPENDIX 3

Dianna James

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Henry Megem

APPENDIX 3

Gibson

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Last Gundy

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Co-Authorship Form

This form is to accompany the submission of any PhD thesis that contains research reported in co-authored work that has been published, accepted for publication, or submitted for publication. A copy of this form should be included for each co-authored work that is included in the PhD thesis. Completed forms should be included at the front (after the thesis abstract) of each copy of the thesis submitted for examination and library deposit (including electronic copy).

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Spool and line data for the brown spiny rat *(Maxomys rajah)*, published in Shadbolt and Ragai (2010) has been reproduced in Chapter 3, Section 3.3.4 (Pp 108 – 111) of this thesis, and the full paper is also included as Appendix 1.

Shadbolt, A., and Ragai, R. (2010) *Effects of habitat fragmentation on the movement patterns and dispersal ability of the brown spiny rat* (Maxomys rajah) *in the Planted Forest Zone of Sarawak, Eastern Malaysia*. Biodiversity Conservation 19: Pp 53- - 541

Please detail the nature and extent (%) of contribution by the PhD candidate:

This paper (Shadbolt and Ragai 2010) was researched and written (100%) by the primary author, and reviewed by the co-author prior to submission to the journal Biodiversity Conservation. The co-author carried out concurrent field research during the primary authors' fieldwork sessions in Sarawak, and also assisted with aspects of the primary authors' fieldwork including: fieldwork logistics, species identification, animal handling, spool-and-line tracking, and provided invaluable advice throughout these fieldwork sessions.

Certification by Co-authors:

If there is more than one co-author then a single co-author vcan sign on behalf of all

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- The above statement correctly reflects the nature and extent of the PhD candidate's contribution to this co-authored work
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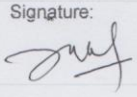
Name: Roslina Ragai Signature: Date: *2014-05-31*



Shadbolt, Antony Bruce, and Roslina Ragai. "Effects of habitat fragmentation on the movement patterns and dispersal ability of the brown spiny rat (Maxomys rajah) in the Planted Forest Zone of Sarawak, Eastern Malaysia." *Biodiversity and conservation* 19, no. 2 (2010): 531-541.